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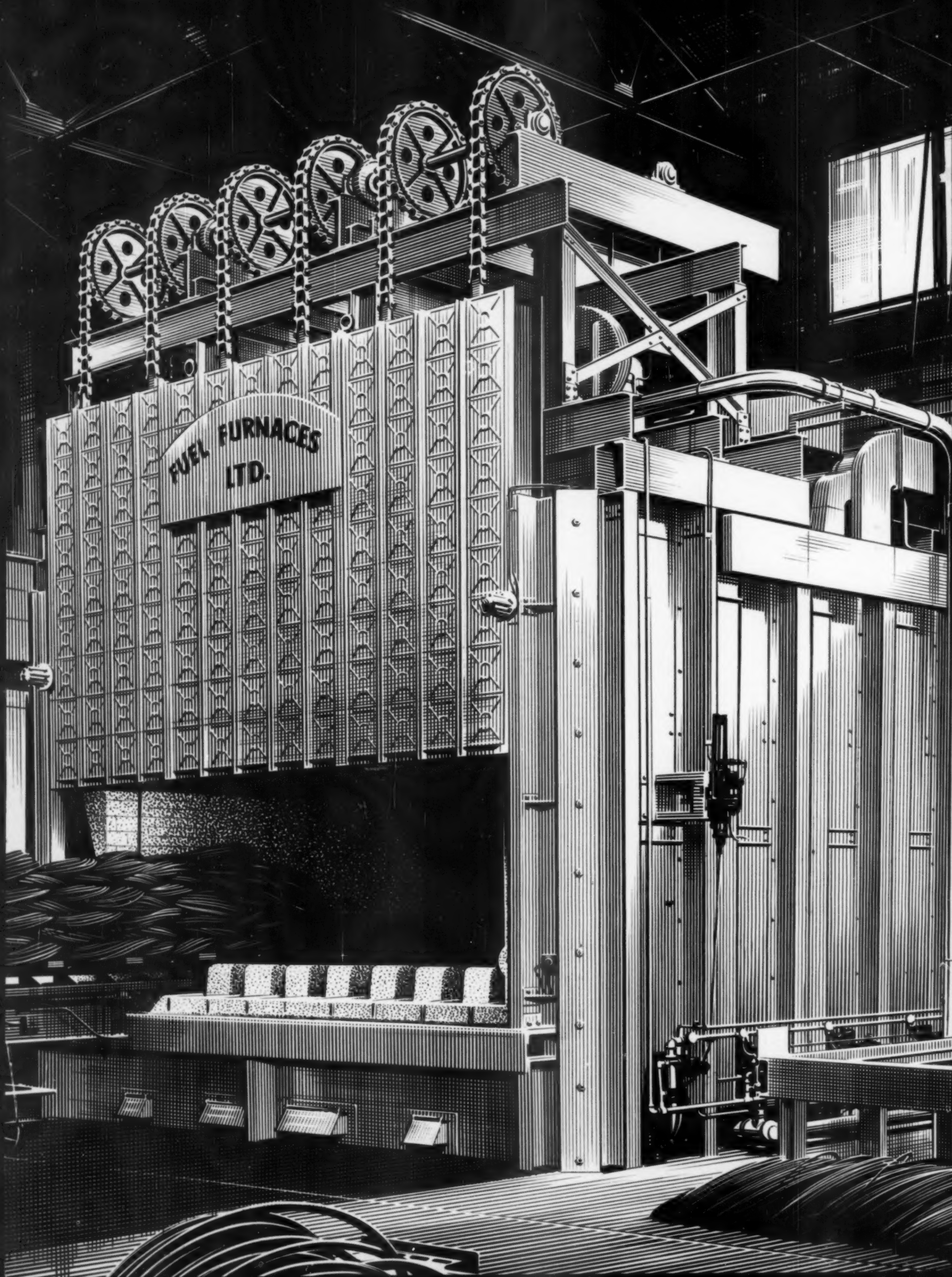
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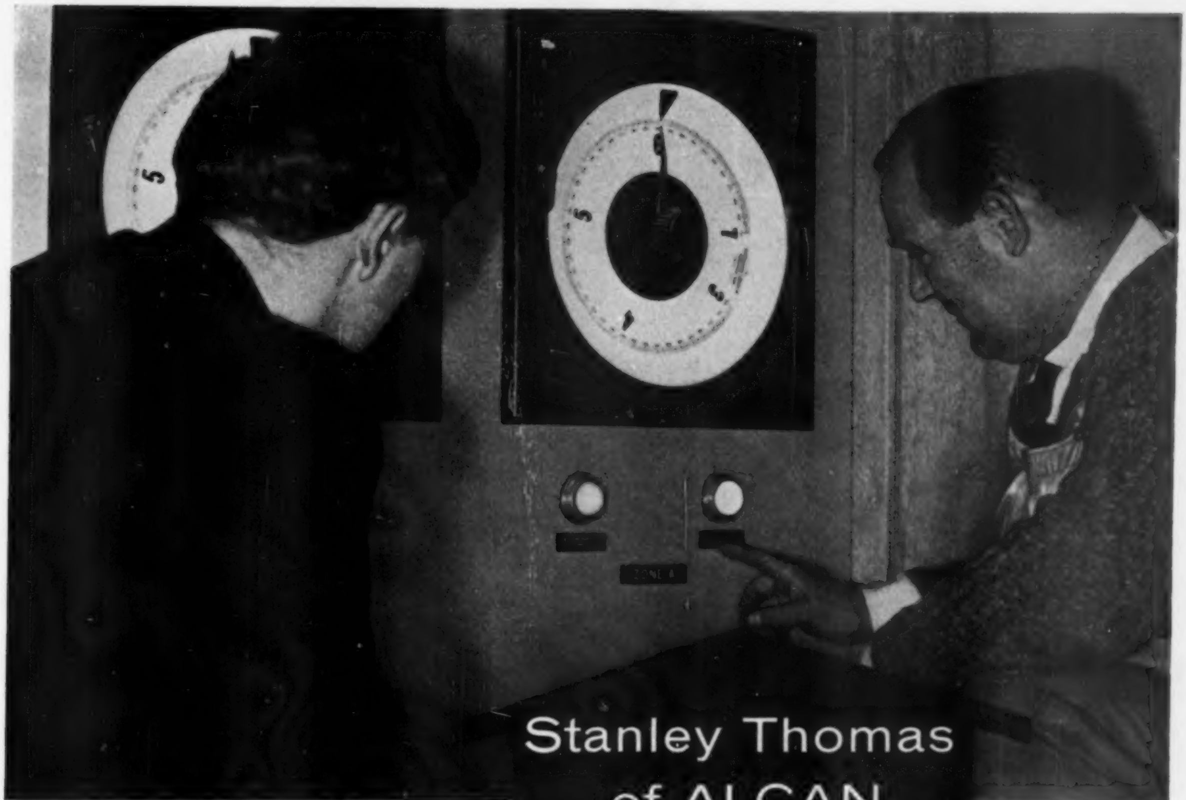

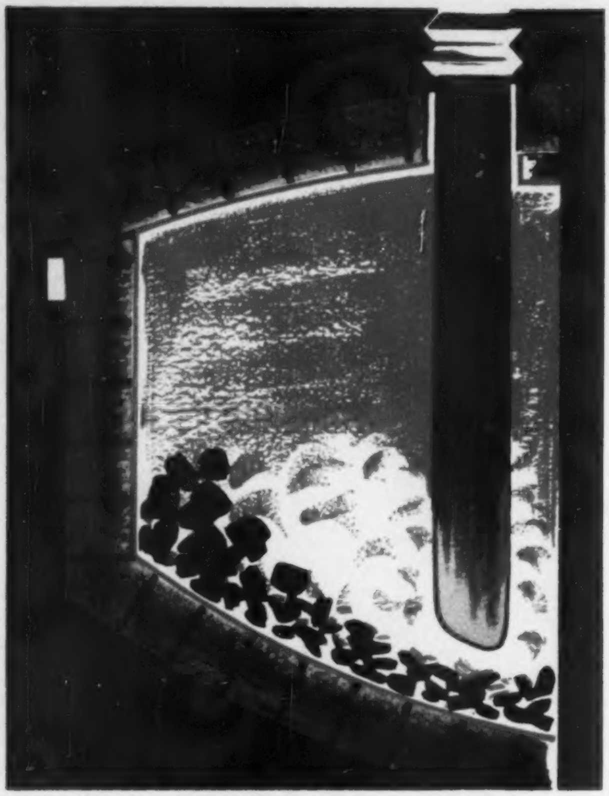

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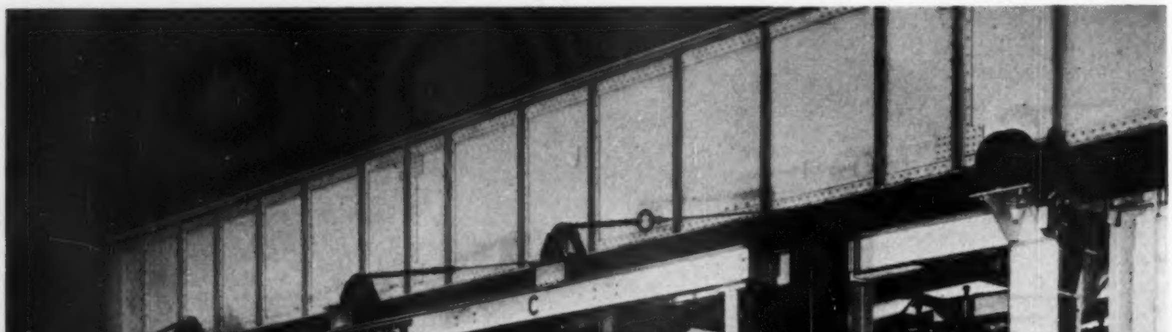

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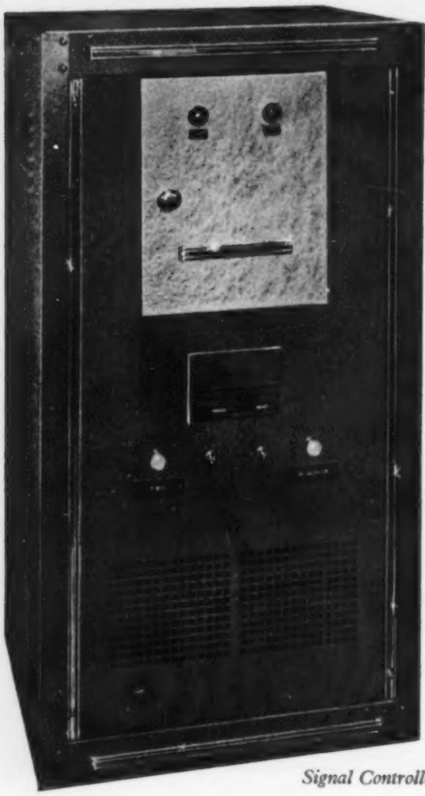

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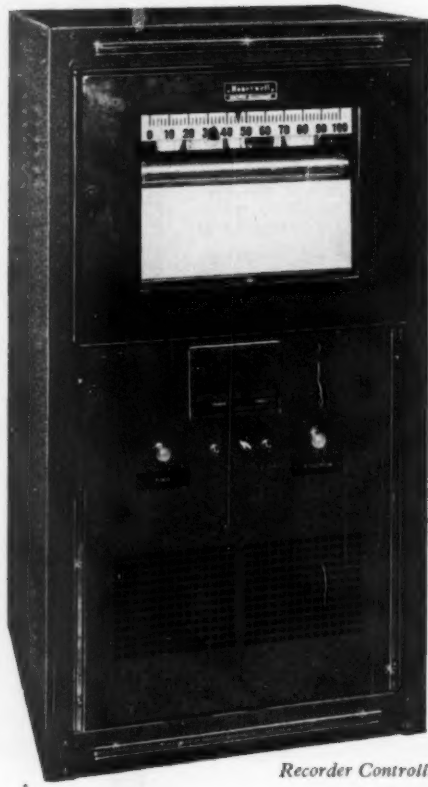

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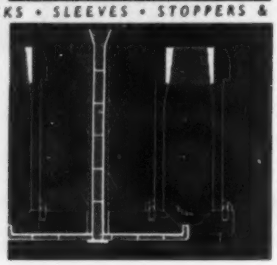

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INCORPORATING THE METALLURGICAL ENGINEER

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LABORATORY METHODS SUPPLEMENT

METALLURGIA

THE BRITISH JOURNAL OF METALS
INCORPORATING THE "METALLURGICAL ENGINEER"

FEBRUARY, 1961 Vol. LXIII. No. 376

Steel Outlook

DESPITE the fact that some industries—the motor car industry is an outstanding example—are no longer having it quite so good as in recent years, the steel industry is quietly confident about the future, according to an article in the January issue of *Steel Review*, so much so that, having spent £900 million on development since the war, it has already decided to spend at least a further £450 million by 1965. From a figure of 26 million ingot tons for 1960, the capacity of the industry will be increased to 27 million ingot tons in 1961 and 30 million ingot tons in 1962, the sharp rise being due to the expansion of sheet production capacity by the completion of the two new wide strip mills. Further developments are likely to raise capacity to over 34 million ingot tons in 1965. As far as can be envisaged at present, these future capacity levels will be more than sufficient to meet likely requirements.

The past year has been one of high activity, crude steel production averaging some 93½% of capacity. The high demand for cars, household durables and food containers continued during the greater part of the year, and the expanding flow of orders from the engineering and constructional industries was met by high outputs of most heavy and light steel products. On the other hand, the demands of the railways, coal mines, shipyards and the oil industry continued at a low level. Rapid rebuilding of stocks of steel by consumers and merchants probably accounted for more than a million tons of the 1960 home deliveries of 21·3 million ingot tons; this compares with a 0·7 million tons stock decline in the previous year. If only stocks were built-up in times of slack demand and reduced at times of peak demand, instead of vice-versa, the steel producers would be a great deal happier. Direct exports reached a post-war record level of 4·2 million ingot tons in 1960, despite the fact that export of certain classes of product was voluntarily restricted to satisfy the high level of home demand, including the requirements for indirect exports. Imports of steel (mainly sheet) amounted to 1½ million ingot tons in 1960 compared with ½ million ingot tons in 1959. Because this high rate of import proved in excess of consumption requirements, sheet stocks held by consumers and merchants increased by 300,000 tons in the first nine months of 1960.

A major factor in the jump in demand in 1960 was stockbuilding, but this is unlikely to be repeated in 1961, when the stock rise is unlikely to amount to more than ½ million ingot tons, which would restore stocks to the March 1958 peak level. The rise in home consumption will probably be small with the trends in the last half of 1960 continuing in the present year. In the capital goods section, where requirements continue to grow, the emphasis is changing from industrial building to plant and machinery as firms begin to equip their new premises. Little change is likely in the demands from the railways and coal mines, and there is some evidence that activity in the shipyards may be lower than last year. As for the consumer goods industries, much will depend on developments in overseas markets and on the Government's policy in stimulating or discouraging home demand. It is believed that some weakness of demand in certain sectors in the beginning of the year might well be followed by a recovery in the second half, or even second quarter. On balance, these factors might result in a net increase of 2–3% in the home consumption of steel, or about ½ million ingot tons above the 1960 level of 20·2 million tons. Expansion in capacity should permit easing of the restrictions in exports and, in spite of the not too encouraging prospects for world demand, there is some hope of exceeding last year's post-war record figures. At the same time, it should be possible to reduce steel imports to the 1959 level, and to obviate imports of scrap and pig iron. This reflects the emphasis laid on the expansion of blast furnace capacity in the industry's development programme, backed by substantial developments of home and overseas sources of ore. On the whole, it seems likely that demand will support an output of about 24½ million ingot tons, or just over 90% of the estimated effective capacity.

The centre of gravity of development is now moving to the strip mill sections of the industry—in particular the Llanwern and Ravenscraig schemes. The first stage of the new Spencer Works being erected by Richard Thomas and Baldwins on a green-field site at Llanwern, Newport, including the 68 in. continuous hot strip mill, the L.D. steelmaking plant, and the 66 in. cold reduction mill, is due for completion in early 1962. Colvilles' new cold reduction mill at Gartcosh is due to come into operation in the latter part of 1961, whilst the 60 in. hot strip mill at Ravenscraig is due to start rolling in the middle of 1962. During 1961 the Steel Company of Wales will also carry out considerable expansion of steelmaking capacity at its Abbey Works and install the new 2-strand continuous casting plant for slabs, whilst John Summers is making substantial additions to its sinter and rolling capacity. Apart from the strip mill developments, the outstanding developments due for early completion are the additions of universal beam mill stands to the heavy section mills at Colvilles' Lanarkshire Works, South Durham's Cargo Fleet Works and The United Steel Companies' Appleby-Frodingham Works. Billet capacity will be expanded by the completion of the two new rotor furnaces for pre-refining and the commissioning of the new continuous billet mill at Richard Thomas and Baldwins' Redbourn Works. Other important developments include the new melting shop at Consett, with two L.D. and two Kaldo vessels, and the completion of South Durham's new South Works by the addition of a blast furnace and further steelmaking capacity.

As a result of these developments, the United Kingdom should have, by 1962, a steel production capacity

exceeding 30 million ingot tons. The scale and speed of this development will exceed anything planned for this period on the Continent, where a capacity increase of 7½% of the 1960 figure is expected by 1962, as compared with a figure of 17½% for the U.K.

The further developments in Britain's steel industry—which include major schemes at Park Gate, Dorman Long, English Steel, Steel, Peech and Tozer, and Appleby-Frodingham—will continue to place increasing emphasis on the use of oxygen in new and existing steelmaking processes and, where appropriate, on electric steelmaking. Present plans provide for a steelmaking capacity exceeding 34 million ingot tons a year by 1965, which should ensure that the industry can meet the probable average long-term demand—say, about 30 million tons in the middle 'sixties—and can accommodate reasonable medium-term fluctuations in requirements as well as stronger seasonal movements in particular sectors. At the same time as expansion proceeds, increased efforts will be made to improve efficiency and to reduce those costs within the industry's control so as to improve the competition power in world markets, not only of the steel industry itself, but of all those industries dependent on it for raw materials.

Meeting Diary

1st March

Institute of British Foundrymen, London Branch (Southampton Section). "Foundry Sands and Moulding Materials," by W. B. Parkes. Technical College, St. Mary's Street, Southampton. 7.30 p.m.

Institute of Welding, Manchester and District Branch. "Methods Adopted by a Large User when Purchasing Welded Equipment," by E. Fuchs and W. Ashworth. Reynolds Hall, Manchester College of Science and Technology. 7.15 p.m.

2nd March

Institute of Metals, Birmingham Local Section. "Rating Sheet Metal Formability by Press Performance," by D. H. Lloyd. College of Technology, Gosta Green, Birmingham. 6.30 p.m.

Institute of Metals, London Local Section. "Progress in the Electron Theory of Metals," by J. A. Catterall. 17 Belgrave Square, London, S.W.1. 6.30 p.m.

Leeds Metallurgical Society. "Grain Size—Three quarters of the Key to Strength " by Professor N. J. Petch. University Staff House, University Road, Leeds. 6.30 p.m.

6th March

Institute of British Foundrymen, Sheffield Branch. "Running, Gating and Feeding of Blackheart Malleable," by W. J. Campbell. Technical College, Pond Street, Sheffield. 7 p.m.

Institute of Metal Finishing, North West Centre. "Chromate Treatments of Metals." Engineers' Club, Albert Square, Manchester. 7.30 p.m.

7th March

Institute of Metals, Oxford Local Section. "Novel Methods of Forming Metals," by J. F. Wallace. Cadena Cafe, Cornmarket Street, Oxford. 7.15 p.m.

Institute of Metals, South Wales Local Section. "Fracture of Metals," by K. E. Puttick. Metallurgy Department, University College, Singleton Park, Swansea. 6.30 p.m.

Sheffield Metallurgical Association. "The Problems of Ferro-Alloy Analysis," by G. M. Holmes. B.I.S.R.A. Laboratories, Hoyle Street, Sheffield 3. 7 p.m.

8th March

Manchester Metallurgical Society. "Solidification and Structure of Cast Iron," by I. C. H. Hughes and W. Oldfield. The Manchester Literary and Philosophical Society, George Street, Manchester. 6.30 p.m.

Society of Chemical Industry, Corrosion Group. "Metal Spraying for the Protection of Bridge Structures," by J. D. Thompson. The Technical College, Gladstone Street, Darlington. 8 p.m.

9th March

East Midlands Metallurgical Society. "The Metallurgy of the Steam Turbine," by L. E. Benson. Faculty of Applied Science, Clifton Boulevard, The University, Nottingham. 7.30 p.m.

Liverpool Metallurgical Society. "Creep Deformation," by D. M. McLean. Department of Metallurgy, The University of Liverpool. 7 p.m.

13th March

Institute of Metals, Scottish Local Section. "Metallurgy and Musical Instruments," by W. H. Tait, followed by the Annual General Meeting. Institution of Engineers and Shipbuilders, Elmbank Crescent, Glasgow C.2. 6.30 p.m.

14th March

Institute of British Foundrymen, London Branch (Slough Section). "Art Bronze Foundling," by A. L. Parrott. Lecture Theatre, High Duty Alloys, Ltd., Slough, 7.30 p.m.

Sheffield Metallurgical Association. "Creep Relaxation," by J. A. Stafford. B.I.S.R.A. Laboratories, Hoyle Street, Sheffield 3. 7 p.m.

15th March

North East Metallurgical Society. "Properties of Metals at Very Low Temperatures," by C. J. Adkins. Cleveland Scientific and Technical Institution, Corporation Road, Middlesbrough. 7.30 p.m.

16th March

Institution of British Foundrymen, London Branch (Beds. and Herts. Section). "Experiences in Making Moulds in a Mechanised Foundry," by H. Pinchin. K. and L. Steel-founders and Engineers, Ltd., Letchworth. 7.30 p.m.

Institute of Metals, Birmingham Local Section. "Choosing a Stainless Steel," by H. T. Shirley. College of Technology, Gosta Green, Birmingham. 6.30 p.m.

20th March

Institute of British Foundrymen, London Branch (East Anglian Section). "Accuracy in Moulds and Cores," by W. B. Parkes. Lecture Hall, Public Library, Ipswich. 7.30 p.m.

Sheffield Metallurgical Association. "Technologists as Successful Managers," by R. Coverdale. B.I.S.R.A. Laboratories, Hoyle Street, Sheffield 3. 7 p.m.

21st–23rd March

Institute of Metals. Spring Meeting, Church House, Great Smith Street, London, S.W.1.

21st March

Sheffield Metallurgical Association, Refractories Group. "Recent Developments in Steelmaking Techniques," by Emrys Davies. B.I.S.R.A. Laboratories, Hoyle Street, Sheffield 3. 7.30 p.m.

West of England Metallurgical Society. "Physical Methods of Analysis," by K. M. Bills. The College of Technology, Ashley Down, Bristol 7. 7.30 p.m.

22nd March

Institute of British Foundrymen, London Branch. "New Ideas in Melting," by W. B. Lawrie. Constitutional Club, Northumberland Avenue, London, W.C.2. 7.30 p.m.

23rd March

Southampton Metallurgical Society. Annual General Meeting followed by "Metallurgy of Ferrous Welding " by R. G. Baker. Southampton University. 7.15 p.m.

24th March

West of Scotland Iron and Steel Institute. Symposium on Heat Treatment. Short papers by F. Darroch, D. M. Clinton and D. M. Syme. 39 Elmbank Crescent, Glasgow. 6.45 p.m.

28th March

Sheffield Metallurgical Association. "The Role of Ferro-Alloys in Modern Steelmaking Developments," by A. M. Sage. B.I.S.R.A. Laboratories, Hoyle Street, Sheffield, 3. 7 p.m.

Society of Chemical Industry, Corrosion Group. "The Resistance of Aluminium to Supply Waters," by H. P. Godard; and "Behaviour of Aluminium in Modern Power Station Condensate Water," by E. A. G. Croom and D. Hastings. The Crown Hotel, Banbury. 4 p.m.–6.30 p.m.

Stress-Relieved Aluminium Alloy Plate for Aircraft

By A. J. Clark, M.A.,* A. R. Martin, B.Sc., A.R.S.M.†
and L. E. Steele, M.Sc., A.I.M., M.I.B.F.†

The use in aircraft construction of integrally stiffened parts machined from plate has led to a demand for large thick plates in strong aluminium alloys. This development requires the plate to be sound and substantially free from stress to obviate distortion on machining. The method of production and the means adopted to ensure that the final product is of satisfactory quality are described here.

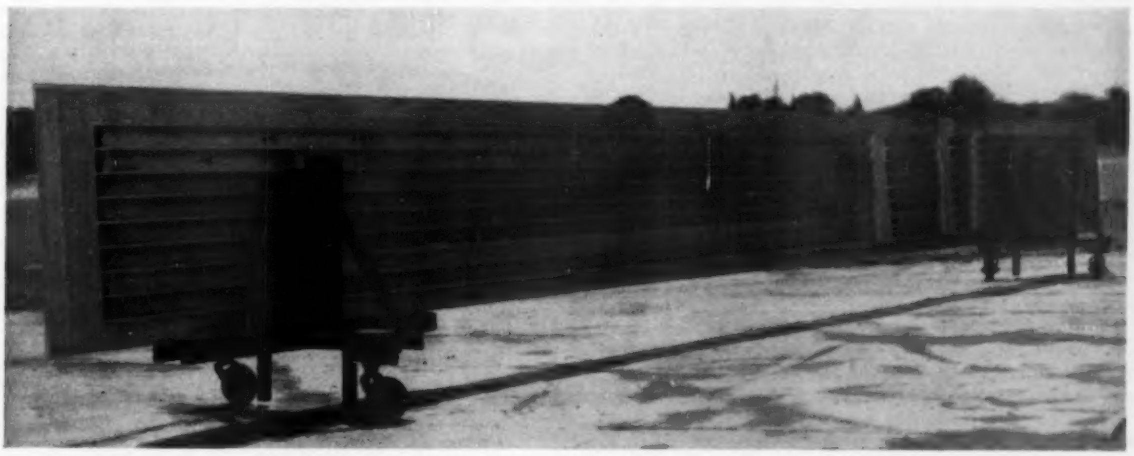
THE modern design philosophy of integral construction, whereby a component is designed to be machined from the solid instead of assembled from a variety of parts, has brought about a radical change in airframe production methods during the past decade. When the trend towards integral construction first became apparent, it was thought that such components could best be produced by die forging, followed by machining, and in the U.S.A. very large forging presses were installed for this purpose. However, several disadvantages were encountered, notably the very high cost not only of forging equipment but also of dies, which could be justified only by very long runs, while delivery times for parts and dies were impracticably long. Moreover, the forged components still required machining and this was only slightly less time-consuming than machining from the solid. Further, the largest presses in Britain could produce an integrally stiffened panel measuring at most only 5–6 sq. ft. in area.

Interest was therefore centred on the logical alternative of machining integrally stiffened parts from thick strong aluminium alloy plate, which could be produced in far larger sizes and on existing equipment. Preliminary experiments in machining unstretched plate resulted in considerable distortion due to the release and redistribution of internal stresses arising from quenching after solution treatment, but this problem was overcome by giving plates a controlled stretch of about 2%, which reduces residual stresses to negligible proportions. While the most spectacular use of stress-relieved plate is for wing and fuselage skins, an application that is becoming increasingly important is as a replacement for large hand or die forgings.

Integral construction has now been widely adopted in Britain, the aircraft in which it is embodied including the Vickers Vanguard, Vickers VC10 and de Havilland Trident airliners and the Blackburn Buccaneer strike aircraft.

Understandably, few aluminium alloy commodities require such strict control at every stage of production or such careful examination before despatch as does aircraft plate. This article presents briefly the technique of production and the methods of testing evolved at the Rogerstone Works of Alcan Industries, Ltd., the suppliers of the greater proportion of the plate used in British aircraft. First, however, a reference to integral construction itself and the treatment of the plate by the aircraft manufacturer.

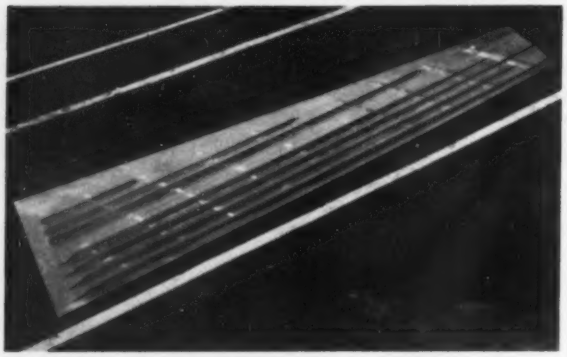
* Sales Development Division, Alcan Industries Limited.
† Technical Department, Rogerstone Works, Alcan Industries Limited.



Courtesy of Vickers-Armstrongs (Aircraft), Ltd.

Fig. 1.—Wing skin panel for the Vickers VC10, incorporating integral stiffening ribs, machined from thick plate. In such components, up to 90% of the original plate may be machined away.

(a)



(b)

Courtesy of Blackburn Aircraft, Ltd.

Fig. 2.—(a) Wing skin panel with integral stiffeners machined from roll-flattened plate; (b) formed wing skin panel with integral stiffeners machined from stretched plate.

Integral Construction

The main advantages of this technique may be summarised as: inherent stability in compression, due to the intrinsic solidity of the structure; a large reduction in the number of parts, joints and rivets, and in the attendant paper work, resulting in a decrease in assembly times and in overall cost; accurate tailoring of the design to known loading conditions and maintenance of the general stress level at a reasonably constant value by suitable local thickening; saving in weight, giving improved performance or increased payload; elimination of fatigue-prone joints; high surface finish and freedom from manufacturing distortions, hence improved aerodynamic characteristics; and suitability for integral fuel tanks, due to absence of joints and seams.

The most common application of integral construction is in the wings, for which several aircraft manufacturers have now adopted the policy of machining from stretched plate skins with integral stiffening ribs, replacing a framework of spars and ribs covered with aluminium alloy sheet. Fig. 1, for example, shows a Vickers VC10 integral wing skin panel that has been produced in this way. For use in components such as this, where up to 90% of the original plate may be machined away, it is vital that the plate should be of the highest quality and not contain defects which could initiate fatigue cracks during service. Although, as will be shown, the aluminium fabricator can provide much wider plates, the width of wing sections or planks is usually limited to about 3 ft. by "fail safe" design techniques which aim to avoid the catastrophic spread of a possible fatigue crack across an entire wing.

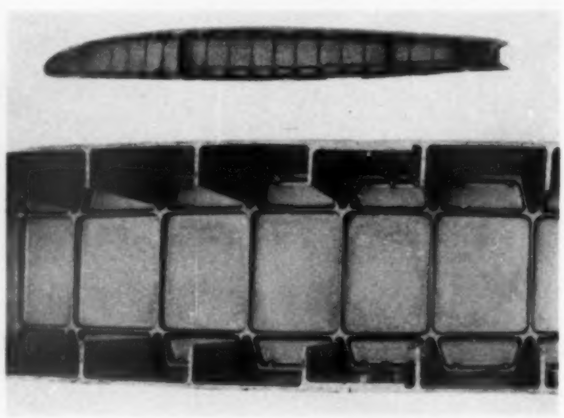
The necessity for using plate that has been stress-relieved by controlled stretching is illustrated by the experience of Blackburn Aircraft, Ltd., in their experiments with roll-flattened plate at a time when stretched plate of the required size was not available in this country. When a wing panel was machined from a piece of this plate measuring 2 in. × 60 in. × 180 in. the residual stresses resulted in the breaking of twelve 0·5 in. diameter holding-down bolts and the panel lifting 3–4 in. along one side.

The difference between controlled-stretched and roll-flattened plate is also illustrated in Figs. 2*a* and 2*b*, showing an integrally-stiffened wing panel machined from each type; while the stretched plate (which was formed to a very slight contour before being photographed) showed no distortion whatever, the roll-flattened material distorted to a degree that made it unusable. Such experience clearly showed the need for the aluminium industry to install equipment capable of controlled-stretching the largest plates likely to be required by the aircraft manufacturers, and this was done by Alcan Industries at their Rogerstone Works.

An early application of integrally machined components by Blackburn Aircraft is presented in Fig. 3, which shows a typical structure built during development of the Buccaneer wing. Both the wing skin planks and the transverse rib member, which was originally made from a forging, have been machined from plate.

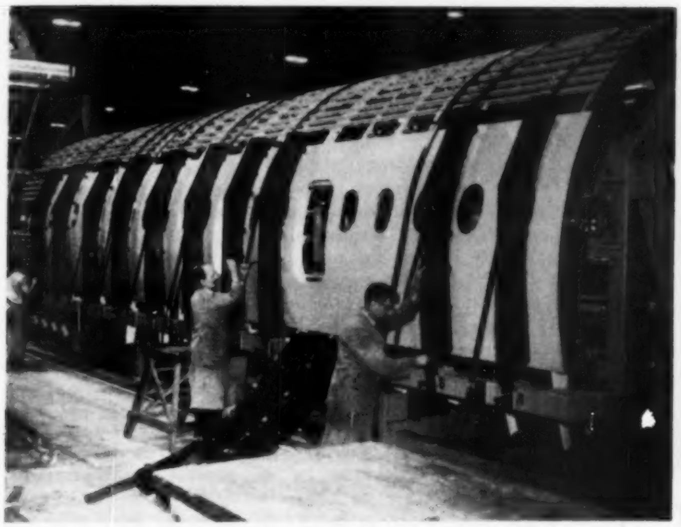
This method of construction is similarly applied to the aircraft fuselage, such as that of the Vickers VC10, illustrated in Fig. 4. In the areas of the window cutouts, the stress levels inevitably tend to be high, but by machining the skin in these areas from solid plates and so providing integral stiffening, instead of using doubler plates as reinforcement, a closer approximation to the ideal of uniform stress is obtained.

The structure of the VC10 as a whole features one of the most extensive applications of integral construction, for about 55% of the basic airframe is represented by major items machined from plate, instead of being



Courtesy of Blackburn Aircraft, Ltd.

Fig. 3.—Wing assembly built by Blackburn Aircraft, Ltd., utilising components machined from thick plate.



Courtesy of Vickers-Armstrongs (Aircraft), Ltd.

Fig. 4.—In assembling the fuselage of the Vickers VC10, one of the 34 ft. long side panels is being mounted into assembling jigs. This panel has been milled from thick plate and curved in a 300 ton press.

fabricated from a multitude of components. Of a total wing surface area of about 5,600 sq. ft., no less than 3,000 sq. ft. are covered with machined planks.

Machining and Forming

The very complex machining problems that integral construction has introduced—necessitating the building of special milling machines—have been simplified by machining the panels flat, with the material in the solution heat treated condition, then forming them before precipitation heat treatment.

The first machining operation is usually a shallow cut from the outer surface of the skin; this provides a machined reference surface for subsequent machining operations and permits the use of a vacuum chuck (which is itself often made from thick aluminium alloy plate). Milling continues on machines such as those illustrated in Fig. 5, which are used to machine out the integral stringers in Vickers VC10 and Vanguard wing panels. These machines handle plates up to 4 in. thick by 40 in. wide by 35 ft. long; gangs of up to six cutters are used and the maximum depth of cut is 0·9 in. at 35 in./min.

To remove machining marks that might act as stress-raisers, panels are always finished by honing, vapour blasting, vacu-blasting, or even hand polishing, and at all times the work is protected against the possibility of corrosion. During the sequence of machining operations, therefore, a lanolin-based oil is often used for this purpose, and finished components are usually either Alocromed or anodised and etch primed.

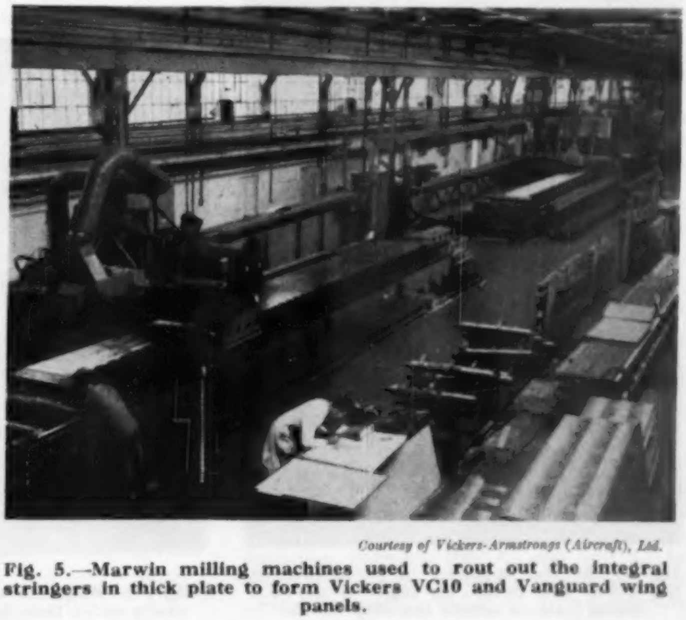
In the case of the Vanguard wing panels, forming is done by shot peening, after the locally thickened areas have first been shaped using the special-purpose hydraulic press shown in Fig. 6. Alternatively, panels may be formed by progressive three-point bending or between shaped wood or plastic dies in a conventional hydraulic press.

Plate Replacing Hand Forgings

In addition to its use in integral construction, thick aluminium alloy plate has extensively replaced machined hand forgings in aircraft production, except where a particular grain flow is of prime importance. Hand forgings require complicated machining schedules, and there is a risk of distortion and cracking during machining even after precautions have been taken to avoid unsatisfactory residual stresses. Stretched plate not only offers greater freedom from distortion and less risk of stress-corrosion and fatigue troubles, but also reduced costs of raw material and production. Whereas, with hand forgings, the initial cut has to be carried out in the annealed condition, followed by solution heat treatment, correction of distortion, final machining and ageing, the stress-relieved plate can be satisfactorily machined in the fully heat treated condition in which it is supplied.

Alloys and Sizes

The aluminium alloys used for thick plate are those that have found application by the British aircraft industry over a considerable number of years in the form of sheet, extrusions and forgings. They include alloys of the aluminium–4½% copper–1½% magnesium type (covered by no relevant British Standard or D.T.D. specifications, but supplied by Alcan Industries as



Courtesy of Vickers-Armstrongs (Aircraft), Ltd.

Fig. 5.—Marwin milling machines used to rout out the integral stringers in thick plate to form Vickers VC10 and Vanguard wing panels.

Courtesy of Vickers-Armstrongs (Aircraft), Ltd.

Fig. 6.—Locally thickened areas of a wing skin for the Vickers Vanguard being formed on a special-purpose hydraulic press.

Noral 24S); the aluminium-copper-silicon-magnesium alloys conforming to the D.T.D. 5010 and 5020 specifications (Noral B26S); and the aluminium-zinc- magnesium-copper-chromium alloy conforming to D.T.D. 5050 (Noral M75S). In the production and use of these alloys the aluminium and aircraft industries have together acquired a wealth of experience over the years.

The aluminium industry has the capacity to produce thick controlled-stretched plate up to 200 sq. in. in cross section and up to 50 ft. in length. The third limiting factor is the weight of the finished plate, which will normally be of the order of 2,800 lb., but in certain specific instances it may be possible to exceed this figure. The provision of such material has been made possible by the installation of new equipment at Alcan Industries' Rogerstone Works during the past few years. The basis for modern plate production was laid at Rogerstone with the installation in 1950 of a hot-line headed by a 96-in. hot mill. Following the modernisation of the hot line last year, that mill is still in position and can still be used for plate rolling, although it is preceded by a 144-in. mill not only of greater width but also of greater power. In 1958, a whole new plant was opened for the finishing and inspection of aircraft plate thus rolled, comprising a heat treatment furnace, 4,000 ton stretcher, plate saw and ultrasonic inspection equipment.

Production

The production of thick plate requires very stringent control at all stages of melting, casting and fabrication, if the high quality and the required mechanical properties are to be achieved consistently. In the brief description of the production of plate that follows, attention will be drawn to the control exercised at each stage. Control by inspection, which is equally important, will be dealt with under a separate heading.

Remelting.—Using pig imported from Canada. remelting and alloying is carried out in glazed, refractory-lined pressure-controlled furnaces of 36,000 lb. capacity, fired by self-proportioning oil burners and mechanically fed by pneumatic charging machines. On completion of melting, which is operated on a batch system, the melt is sampled and its composition checked by a direct-reading spectograph, for great importance is placed on the maintenance of the melt composition.

Fig. 7.—In the sequence of preforging in the 4,000 ton press, an ingot is given a sizing pass to obtain the slab width.

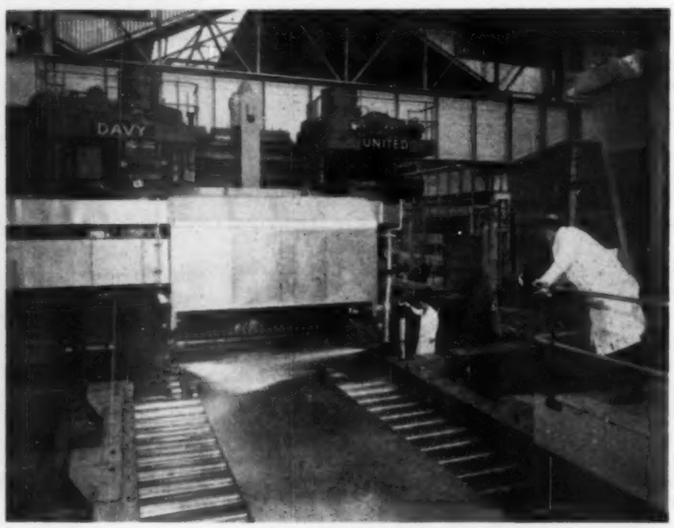


Fig. 8.—Rogerstone's 144-in. mill is capable of rolling plate much wider than is at present required in aircraft manufacture.

As is common practice, the melt is degassed with gaseous chlorine, but here the conditions required to prevent excessive magnesium losses are quite critical, and the closest attention is paid to temperature control at all times. If the hydrogen content of a melt is above a critical "threshold" value the cast ingot will be porous; degassing is carried out to reduce the hydrogen content below this value (which varies from one alloy to another). The gas content of the melt is checked by means of reduced-pressure equipment using samples taken at the launder towards the end of each casting operation. The absence of gas porosity in the solidified reduced-pressure test sample is in good agreement with the attainment of a melt gas content below the threshold.

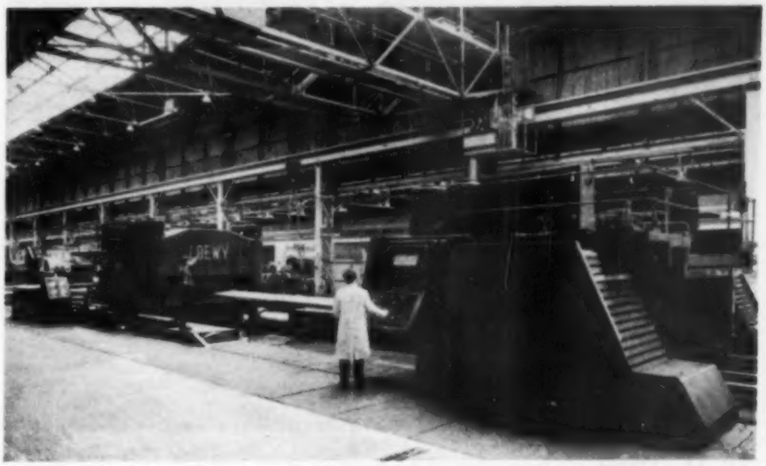


Fig. 9.—A length of thick aircraft plate being manoeuvred into position in the 4,000-ton stretcher.

Casting.—After degassing, the metal is poured by the direct chill (semi-continuous casting) process to the required ingot size, several ingots usually being cast simultaneously. Each of the casting variables—pouring temperature, pouring speed, ram speed, level and temperature of the flood water, as well as the design and condition of the mould—has an important bearing on the quality of cast stock. Failure to control any of these factors within close limits leads to cracking and poor surface condition with its attendant defects; they are therefore given strict attention and, as a further check on quality, sections are taken through the thickness of the ingot, fully heat treated and mechanically tested.

Preforging and Preheating.—To ensure that only sound material passes forward for rolling, all ingots are ultrasonically inspected; and to provide a uniform surface and so ensure that even the smallest defects are picked up, each ingot is first scalped. A large milling machine scalps both faces of a large ingot in less than five minutes.

Plate up to 2½ in. thick, hitherto rolled on the 96-in. mill, has exhibited satisfactory mechnical properties, but to produce these in thicker plate it is essential to preforge the ingot and so ensure that, on rolling, the work will penetrate to the core of the material. Preforging is done on a 4,000 ton hydraulic press at the company's Forging Division at Handsworth, Birmingham (Fig. 7). The ingots are preheated and the temperature is checked at the beginning and during the forging operation using contact pyrometers. The forging technique is such that recrystallisation effects are suitably controlled, and, in particular, critical strains are avoided since they cause recrystallisation to a coarse-grained structure in final heat treatment.

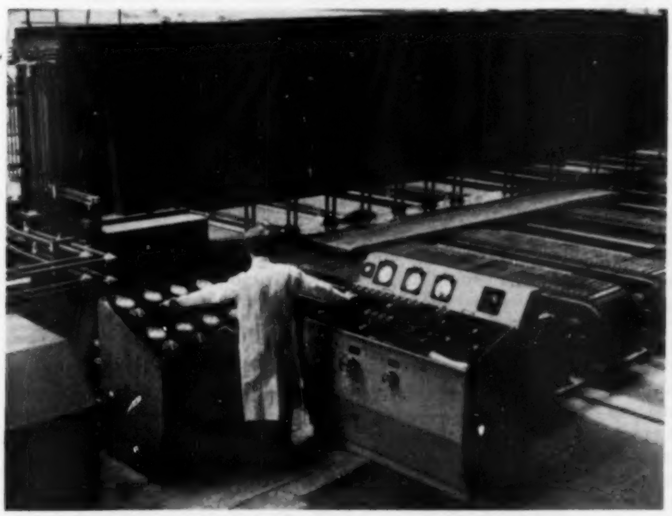


Fig. 10.—The plate is accurately cut to size on the plate saw, being firmly held down by hydraulic jacks.

Before rolling, preforged ingots are again scalped to remove surface imperfections resulting from forging and all billets are preheated. Electrically-heated tunnel-type furnaces are preferred since the highest practical preheating temperatures are required, and this type of furnace provides the very accurate temperature control essential to avoid overheating.

Hot Rolling.—For hot rolling, use is made of either the newly-installed 144 in. mill (Fig. 8) or the 96 in. mill, which is in fact the next in the hot line. During preforging, ingots are normally forged to the required width for rolling straight down to plate, without cross rolling.

Heat Treatment.—The furnace in which this operation is carried out is designed to heat treat loads of plate up to 10 tons in weight and up to 50 ft. in length, and for operation between 100° C. and 550° C. to cope with both solution treatment and artificial ageing. It is a bottom-loading

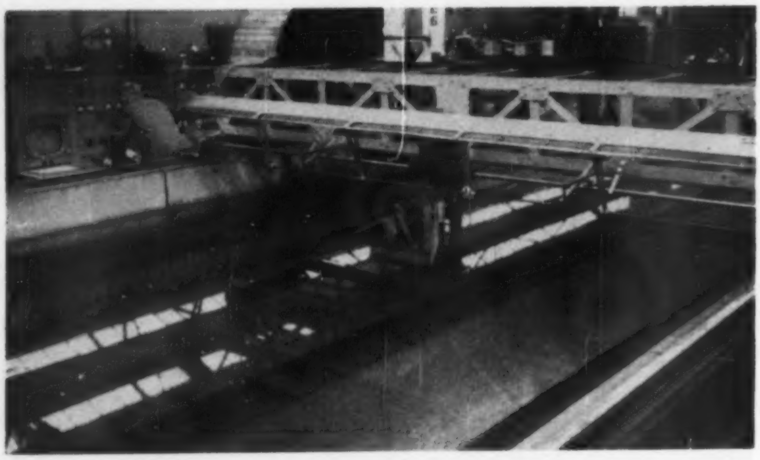


Fig. 11.—Ultrasonic inspection of the finished plate, using the Curtiss-Wright Immerscope.

furnace, electrically-powered, fully air-circulated and stainless-steel lined. The quench tank is sunk into the floor immediately below the furnace and equipped with circulating pumps. Low thermal capacity is an important feature facilitating rapid change of furnace temperature, for example in alternating solution heat treatment and ageing operations.

Stretching.—The stresses set up in heat treatment are relieved by the application of a controlled stretch of $2 \pm \frac{1}{2}\%$ in the 4,000 ton stretcher, which can handle aircraft plate up to 50 ft. long, 10 ft. wide, and 200 sq. in. in cross-sectional area (Fig. 9), although moderate overloads are occasionally permissible.

Sawing and Inspection.—The saw used for trimming the plate to size must keep the material squarely and firmly secured during the cutting operation. This is achieved by means of eighteen pairs of hydraulic jacks, one set holding the plate and the other the offcut. The saw is capable of cutting plate 6 in. thick at the rate of 90 in./min. (Fig. 10).

Finally, every finished plate is ultrasonically inspected (Fig. 11).

Quality Control by Inspection

The greatest importance is placed on the ultrasonic inspection of both cast ingot and finished plate, and also on the tensile testing of the finished product. The high quality of the plate very largely depends on these test procedures and they are worth mentioning at some length.

Ultrasonic Inspection of Cast Ingots.—Defects in the cast material will be carried through into the final plate, and in view of the change of shape will be spread out. All ingots are therefore ultrasonically inspected, using the Curtiss Wright Immerscope, after they have been scalped to enable the probe to pick up the smallest defects. A 4 in. wide 5 Mc./s. probe is used.

Experience shows that ingots giving ultrasonic indications less than $\frac{3}{64}$ in. will yield finished plates meeting ultrasonic inspection standards. Porosity resulting from either shrinkage or unsuccessful degassing is thrown up as an indefinite trace, the peak level of which should also be less than $\frac{3}{64}$ in.

If melting and casting techniques have been correctly followed, defects in cast ingots will normally be confined to the ends. This is due to turbulence at the start of the pour and to inadequate feeding at the end (the latter producing shrinkage in the head of the ingot). Following inspection, therefore, the ingots are marked to indicate the amount that must be discarded from the head and tail. From records that have been kept of these offcuts, it has been possible to determine the optimum discard that should be allowed in planning the cast length; obviously, the more that is cut off, the poorer will be the recovery of usable length to cast length, while the smaller the discard allowed the greater will be the possibility of rejecting ingots on ultrasonic inspection. A balance has to be struck between these opposing requirements, as illustrated in Figs. 12*a* and 12*b*.

Ultrasonic Inspection of Finished Plate.—For accurate assessment of the defects in finished plate, a high degree of resolution is desirable, so $\frac{3}{4}$ in. diameter 10 Mc./s. quartz or lithium sulphate probes are used. Of these, quartz crystals afford a markedly higher sensivity, but lithium sulphate, because of its greater damping capacity, offers higher resolution. The Immerscope is capable of being used at higher frequencies, but whilst the resolution improves as the frequency is increased, absorption also increases with the frequency so the sensitivity is much reduced.

The instrument is checked against reference blocks containing artificial defects, which are drilled flat-ended holes ranging from $\frac{3}{64}$ in. to $\frac{13}{16}$ in. in diameter, at various depths. The blocks were made from 3 in. hexagonal extruded bar conforming to D.T.D. 5054 and were prepared and calibrated by Alcan Industries' associates Aluminium Laboratories, Ltd., to meet the draft standard suggested by the Aluminium Industry Council. The reference blocks are protected by anodising and are colour coded for identification. Frequent cross checks are being carried out with equipment operated by Aluminium Laboratories.

To set up the equipment for the examination of the plate, the gain and sensitivity-time compensator controls are set so that artificial defects $\frac{3}{64}$ in. and $\frac{5}{64}$ in. in diameter can readily be identified in the plate thickness range under examination. The sensitivity-time compensator corrects for the increasing attenuation of the pulses as the path length of the ultrasonic beam increases, and thereby provides roughly the same indication on the "A" scan for, say, a $\frac{3}{64}$ in. artificial defect near to the top surface and near to the bottom surface of a thick plate. The automatic flaw alarm can be preset to any desired level and will stop the automatic scanning head so that the position and size of the defect can be noted. It is a feature of the automatic alarm circuit that it must

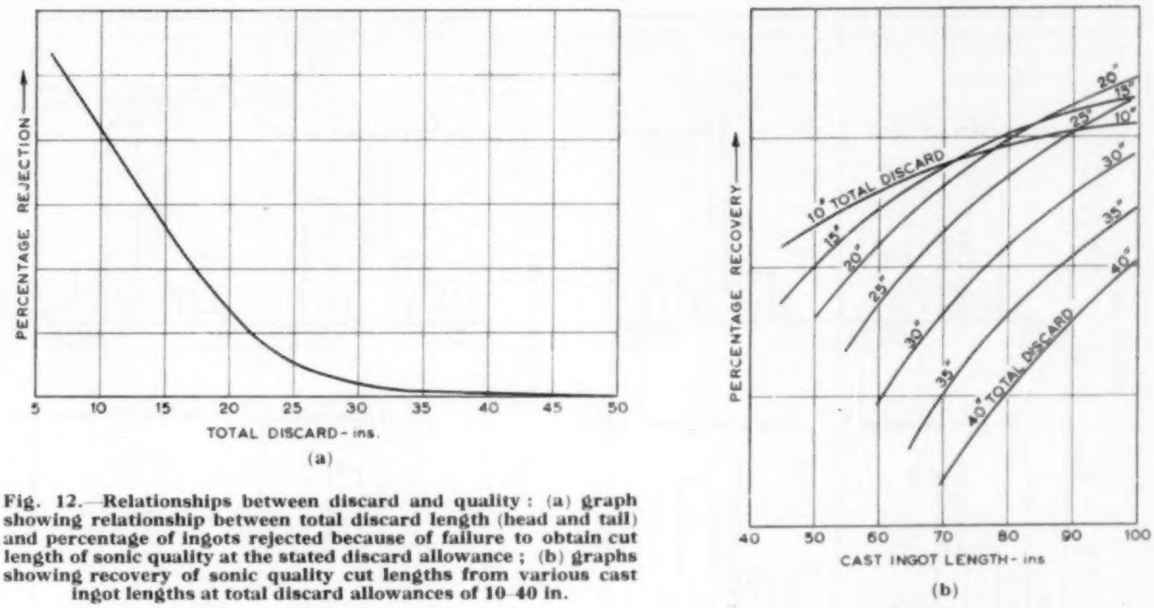


Fig. 12.—Relationships between discard and quality: (a) graph showing relationship between total discard length (head and tail) and percentage of ingots rejected because of failure to obtain cut length of sonic quality at the stated discard allowance; (b) graphs showing recovery of sonic quality cut lengths from various cast ingot lengths at total discard allowances of 10–40 in.

be inoperative whilst the trigger (or top surface) pulse decays to below the alarm level, for otherwise the alarm would operate continuously. The alarm circuit is therefore inoperative for a time equivalent to a distance of ½ in. from the top surface of the plate. It is for this reason that plate of 1 in. thickness and under must be scanned from both faces. There will, of course, be a central dead zone in plate less than ½ in. thick.

It could be said that plate of any thickness should be inspected from both faces, and certainly for complete coverage this would be essential. However, as already mentioned, thick plate is subject to considerable machining, and usually there is only one face that becomes a "skin" face (that is, forms the aircraft skin). Crack detection from one face only is therefore satisfactory, provided that either the "skin" face or the face from which inspection has been carried out is clearly indicated.

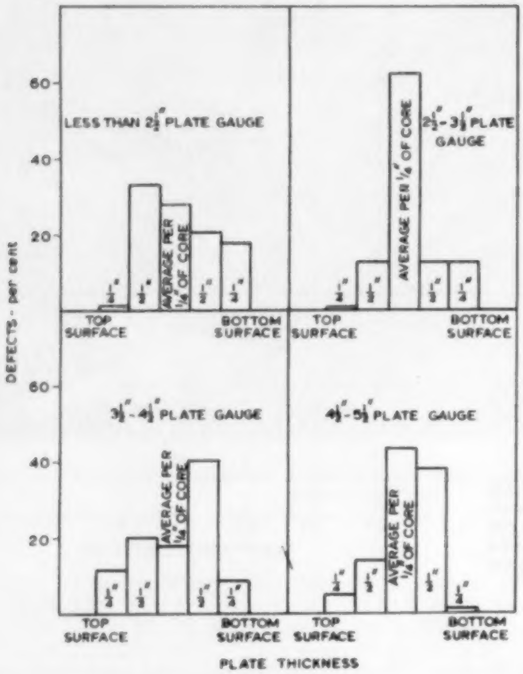
Ingot porosity resulting from shrinkage or dissolved hydrogen concentrates in the core of the plate and will be detected from either face. On the other hand, recent survey of the inspection records showed that individual defects are not confined to the core of the plate but are reasonably randomly distributed through the thickness, as shown by a selection of the frequency distributions obtained, illustrated in Figs. 13*a*, 13*b* and 13*c*. A further outcome of this survey shows that when only a few defects are present they are very likely to be small ones. It is only when defects are numerous that there is evidence of larger ones.

Tensile Testing

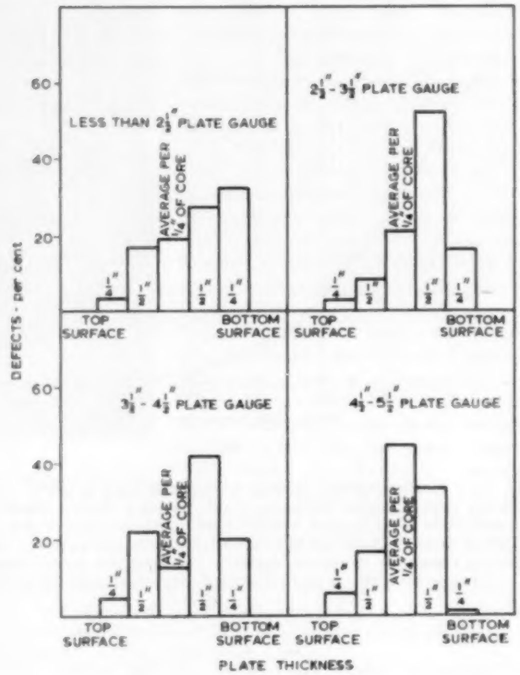
The testing procedure for the release of plates on tensile properties has now been largely standardised. A test block is taken from the centre of the width at one end of the plate, care being taken to clear the stretcher jaw marks, since stretching raises the levels of the longitudinal proof stress and ultimate tensile stress in particular. The longitudinal and long transverse test pieces are taken with their axes in the plane in the centre of the plate thickness, and the short transverse test pieces are taken so that the mid point of their gauge length lies on this central plane.

In the longitudinal and long transverse directions the test pieces will normally be the standard type "C" (B.S.S. 3A4); in the short transverse direction, the largest sub-standard size that can be prepared will be used. In the extreme case of 1 in. thick plate, use is made of the Hounsfield Tensometer, the only disadvantage of which is that the proof stress must be obtained from an autographic record. From thicker plate, screw-end test pieces may be prepared and these are used in conjunction with Baty adaptor grips and a Lindley extensometer. The smaller Baty adaptors accommodate a test piece of 0·159 in. diameter with a gauge length of 0·56 in., which may be taken from plate down to 1¼ in. in thickness. The larger grips accommodate a test piece of 0·282 in. diameter with a gauge length of 1·0 in., which may be taken from plate 2 in. and thicker.

Accurate measurement of the elongation of the smaller sub-standard test pieces presents difficulties which have been largely overcome by the present technique. The parallel portion of the test piece is in fact the gauge length and is machined to a jig. The overall length of the test piece is measured by means of a micrometer, and after breaking, the pieces are reassembled very carefully and the overall length measured again. The difference is expressed as a percentage of the gauge length and not of the overall length. This method assumes that if any elongation of the test piece occurs outside the parallel length (i.e., in the grips) it is negligible by comparison with the extension of the parallel length. This assumption is justified and has been confirmed by cross-checks with A.I.D., Harefield.



(a)



(b)

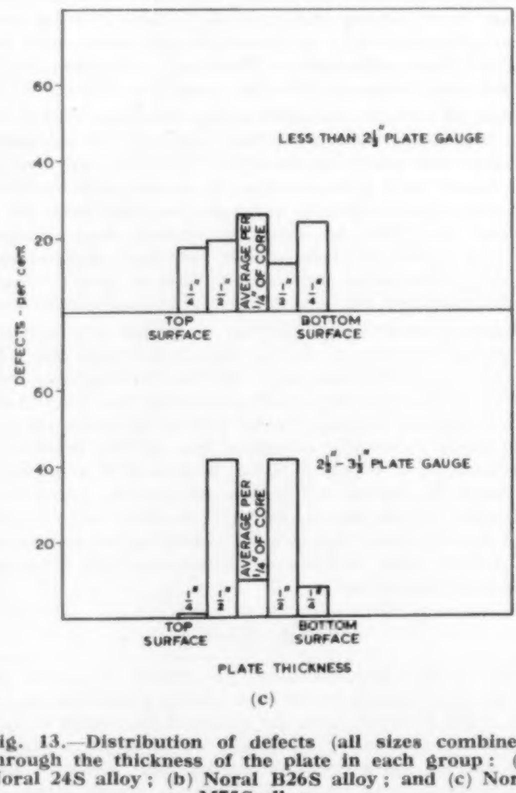
The average properties obtained from plates in the three alloys used are listed in Table I. Records are maintained to allow continuous surveys to be made of the properties and their dependence on such factors as alloy composition and manufacturing conditions. One purpose of these surveys is to ensure that the minimum guaranteed properties are the highest that can be offered to enable the aircraft manufacturers to take the fullest advantage of these materials. It has been possible to establish " between plate " variances for all properties except the lower levels of short transverse elongation, these tending to produce somewhat skew distributions. From this information it is possible to derive the standard deviation for a given property. Knowing the average and the standard deviation, it is possible to calculate realistic specification minimum properties that will yield known rates of rejection. A level of 1% rejection was aimed at for individual properties.

If the nine properties involved were uncorrelated this would result in an overall rejection rate of $100\ (1-0{\cdot}99^9) = 10{\cdot}4\%$. However, most of the properties are correlated and a closer approximation is obtained if the rejection rates for the property most likely to fail in each of the three testing directions are taken into account. In this case the overall rejection rate becomes :

$$100\ (1-0{\cdot}99^3) = 3\%$$

The quantities to be subtracted from the various averages are listed in Table II. These quantities were calculated as follows :

(*i*) A value for the standardised deviate was selected from Table III to give approximately 1% rejection. This value is 2·3.



(c)

Fig. 13.—Distribution of defects (all sizes combined) through the thickness of the plate in each group : (a) Noral 24S alloy ; (b) Noral B26S alloy ; and (c) Noral M75S alloy.

TABLE I.—VARIATION IN PROPERTIES WITH PLATE GAUGE IN ALLOYS NORAL 24S, NORAL B26S (D.T.D. 5020) AND NORAL M75S (D.T.D. 5050)

Rolling Procedure	Test Piece Direction and Type	Plate Thickness (in.)	0·2% Proo fStress (tons/sq. in.)			Ultimate Tensile Stress (tons/sq. in.)			Elongation (%)		
			Noral 24S	Noral B26S (D.T.D. 5020)	Noral M75S (D.T.D. 5050)	Noral 24S	Noral B26S (D.T.D. 5020)	Noral M75S (D.T.D. 5050)	Noral 24S	Noral B26S (D.T.D. 5020)	Noral M75S (D.T.D. 5050)
Rolled Direct from Cast Ingot	Longitudinal	0·5–2·0	25·1	28·3	33·1	31·6	31·2	36·8	14·2	10·7	10·9
		2·0–3·0	24·6	28·1	32·4	31·6	31·3	35·8	13·8	9·1	9·4
	Long Transverse	0·5–2·0	22·2	27·2	31·6	30·1	30·6	36·1	12·4	8·9	9·1
		2·0–3·0	20·7	27·0	29·1	28·0	30·7	33·5	9·8	7·6	6·4
	Short Transverse	0·5–2·0	20·4	26·3	27·3	28·1	30·0	33·4	7·2	4·7	3·6
		2·0–3·0	19·0	25·6	27·1	24·7	29·6	31·4	4·1	4·4	2·9
Rolled from Preforged Ingot	Longitudinal	1·0–3·5	22·8	26·7		29·6	29·8		19·4	12·7	
		3·5–4·5	23·1	26·6		30·3	29·2		16·9	11·4	
		4·5–5·5	22·7	25·9		29·2	29·0		15·7	11·4	
		0·5–2·5			33·1			36·9			12·0
		2·5–3·5			30·1			35·6			11·3
	Long Transverse	1·0–3·5	20·5	26·2		29·7	30·2		16·0	10·2	
		3·5–4·5	19·7	25·8		28·2	29·1		14·4	8·7	
		4·5–5·5	19·4	24·9		27·6	28·5		14·2	9·4	
		0·5–2·5			31·0			36·0			11·7
		2·5–3·5			27·8			34·2			10·5
	Short Transverse	1·0–3·5	19·2	25·8		27·5	30·5		7·5	6·3	
		3·5–4·5	19·0	25·4		27·7	29·5		8·6	5·6	
		4·5–5·5	17·8	24·6		26·0	28·6		7·3	5·0	
		0·5–2·5			29·3			34·5			4·4
		2·5–3·5			25·8			32·7			4·3

(*ii*) The standardised deviate is given as :

$$\text{Standardised Deviate} = \frac{\text{Average Property—Calculated Specification Minimum}}{\text{Standard Deviation}}$$

(*iii*) The calculated specification minimum is obtained by subtracting $2 \cdot 3 \times$ standard deviation from the average.

It would be reasonable to expect that a set of high release properties would reflect a high average level of properties in the plate from which it was obtained. In the same way a low set of release properties would be expected to reflect a low average in the plate represented and to some extent this will be true. However, plates have been cut up for comprehensive tensile survey and the within-plate variances determined. Invariably it is found that the within-plate variances are of the same order as the between-plate variances. More important still, the limits of the ranges of the various properties (both upper and lower) are the same for test pieces cut from a large number of plates as for a large number of test pieces cut from an individual plate. For example, distributions for the nine properties obtained on a survey of a $5\frac{1}{4}$ in. thick Noral 24S alloy plate are illustrated in Fig. 14. The test pieces were cut at five stations along the length of the plate and at three points across the width. At each of these fifteen locations three test pieces were cut with their gauge lengths close to the top surface, the central plane and the bottom surface : this provided a comprehensive survey. The frequency distributions illustrate the overall scatter, but to determine whether or not any systematic variation in properties occurred, three-dimensional diagrams such as that for short transverse elongation illustrated in Fig. 15 were drawn up. These confirmed that the properties were generally lowest in the central plane and in the centre of the width. The first important point established by this work is that taking the release test pieces from the centre of the width and thickness there is

TABLE II—TYPICAL VALUES OF STANDARD DEVIATION USED TO CALCULATE GUARANTEED MINIMUM PROPERTIES.

Alloy	Factor	Values of Factor for		
		0·2% Proof Stress (tons/sq. in.)	Ultimate Tensile Stress (tons/sq. in.)	Elongation (%)
Noral 24S	Standard Deviation	0·95	0·75	1·65
	Average Value minus Calculated Specification Minimum	2·2	1·7	3·8
D.T.D. 5020 and 5050	Standard Deviation	0·95	0·75	1·5
	Average Value minus Calculated Specification Minimum	2·2	1·7	3·4

Note 1—

$$\text{Standardised Deviate} = \frac{\text{Average Value} - \text{Calculated Specification Minimum}}{\text{Standard Deviation}}$$

$= 2 \cdot 3$ for 1% rejection

The specification minimum values have been chosen to give approximately 1% rejection on individual properties. This would be expected to give approximately 3% rejection, taking account of all properties in all directions.

Note 2—

The standardised deviate has not been used to find the minimum short transverse elongation values in the case of D.T.D. 5020 and 5050 alloys. These have been obtained from cumulative distributions.

TABLE III.—TABLE OF RATES OF REJECTION DETERMINED FROM THE STANDARDISED DEVIATE

Standardised Deviate	Rejection Rate (%)	Standardised Deviate	Rejection Rate (%)
0	50	1·6	5·0
0·1	46	1·7	4·5
0·2	42	1·8	3·6
0·3	38	1·9	2·9
0·4	34	—	—
0·5	31	2·0	2·3
0·6	27	2·1	1·8
0·7	24	2·2	1·4
0·8	21	2·3	1·1
0·9	18	2·4	0·8
—	—	2·5	0·6
1·0	16	2·6	0·5
—	—	2·7	0·3
1·1	14	2·8	0·3
1·2	12	2·9	0·2
1·3	10	3·0	0·1
1·4	8	—	—
1·5	7	—	—

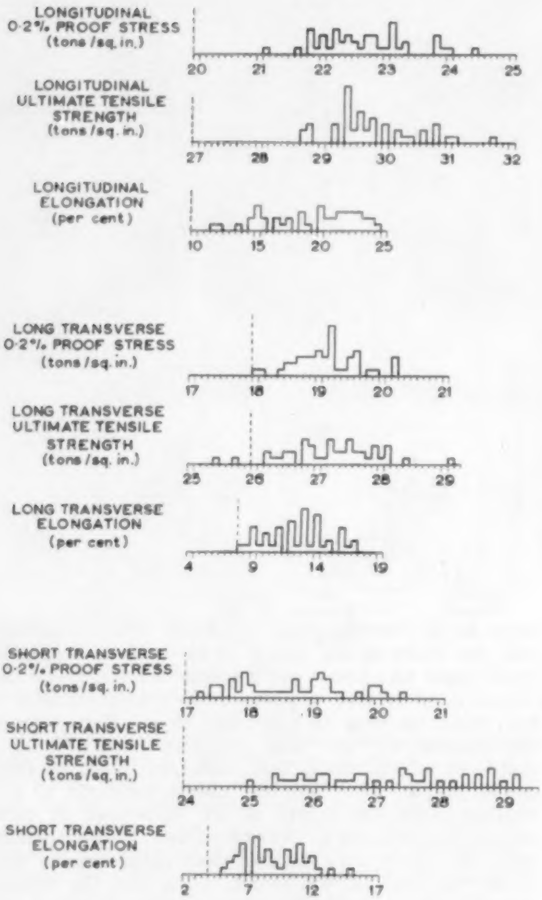


Fig. 14.—Distribution of properties obtained on testing 5½ in. thick Noral 24S alloy plate: specified minima shown dotted.

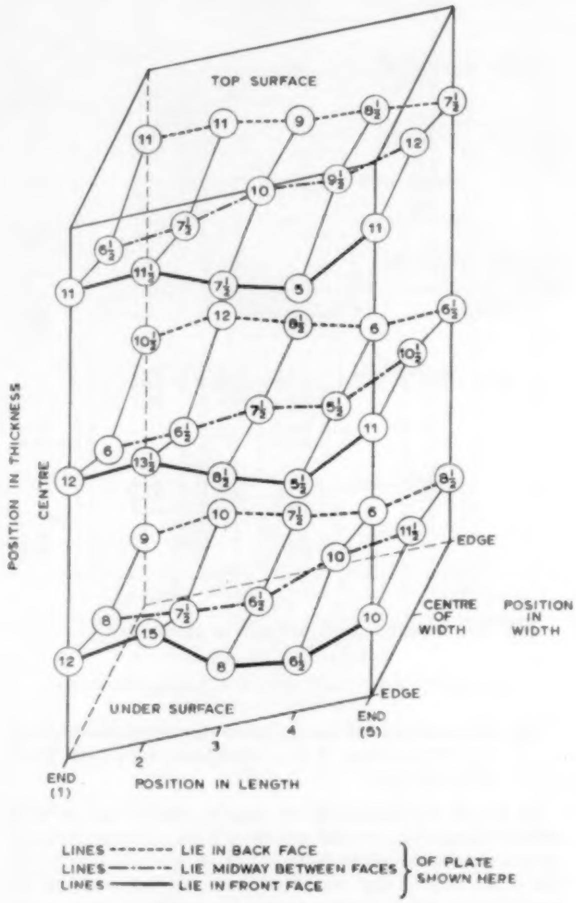


Fig. 15.—Short transverse elongation values at various points relative to the surfaces of the plate. In this sketch the thickness of the plate is greatly enlarged relative to the length and width.

reasonable assurance that the bulk of the plate will have properties exceeding the release levels.

A second and very important implication of this investigation into within-plate scatter is that the minimum guaranteed properties that apply to the release test pieces also apply to the plate. Although release properties at the top end of their range may indicate a high average level in the plate, if the plate were to be subjected to a comprehensive tensile survey properties may be obtained down to the bottom limits of their respective ranges. From time to time it has been suggested that, for particular applications, plates could be selected on the basis of high release properties. Clearly this is not a practical approach since although the release levels are set higher the components will not be as strong as the release properties suggest. The proportion of failures on release tests would also indicate the proportion of tests that would fail to meet these higher release levels if the components were cut up for survey.

This approach to the problem of the production and inspection of aircraft plate is considered to be realistic. Such an approach is vital if the aircraft industry is to be confident not only that plate supplied meets the minimum guaranteed property levels and ultrasonic requirements consistently, but that each plate is consistently uniform within itself.

Croda German Representatives' Visit

The purpose of a recent five-day visit of ten German area sales representatives was to witness the manufacture and sale of Croda products in the United Kingdom in order to tackle better the German market. The programme included a visit to the main Croda, Ltd., factory at Rawcliffe Bridge, a visit to the Croda Research Establishment at Snaith, and discussions and lectures at the headquarters at Cowick Hall. Later the party toured the works of the Rover Car Company's factory at Solihull, where they saw many Croda products in use, before spending a day at the works of The Steel Company of Wales at Port Talbot, Glamorganshire, where they again saw a large number of different Croda products in action. The tour was rounded off by a visit to the well-known cosmetic factory of Yardleys before the party flew off from London Airport to Düsseldorf.

Aluminium and its Alloys in 1960

Some Aspects of Research and Technical Progress Reported

By E. Elliott, A.Met., F.I.M.

Chief Metallurgist, The Aluminium Development Association

Attention is drawn to work published in this country and the U.S.A., reporting research and technical progress in the various aspects of the metallurgy of aluminium and its alloys, including extraction, founding, fabrication, constitution, properties and standardisation. Reference is also made to interesting applications of these materials.

IT may seem anachronistic to begin an article of this nature with a quotation six hundred years old, but, as is often the case, Dan Chaucer[1] says something relevant :—

> " For out of olde feldes, as men seyth,
> Cometh al this newe corn from yer to yere,
> And out of olde bokes, in good feyth,
> Cometh al this new science that men lere."

It is tempting to make the contrast that nowadays one sees old corn in new books ; but it is the task of the technologist to winnow out the grain from the chaff, and so continue the bread and butter task of assembling knowledge about aluminium.

One book from which the reader should make no selection is Professor Aitchison's[2] " History of Metals " ; he should read both volumes of this beautiful, exciting work from cover to cover, pausing only to look at the illustrations, particularly those devoted to metals in antiquity.

Production

The increase in world production of aluminium continues, not steadily but nevertheless rapidly, and it is interesting to look back to the days when it was a semi-precious metal. A brief account[3] has been given of Péchiney's entry into the industry with his sodium displacement process ; this despite the fact that he regarded the metal as having lightness as its only merit, and being otherwise detestable. Indeed, he was a rather strange character, and is said to have turned down Héroult's electrolytic process on being beaten by that inventor at billiards.

Aluminium production in Norway began more than fifty years ago, and now exceeds 150,000 tons yearly. The various extraction works in that country have been described[4] and illustrated ; a large proportion of the production is sold abroad, and Norway is second only to Canada as an exporter of virgin metal. Japan, on the other hand, uses at home[5] most of the aluminium that it extracts ; bauxite is imported from Malaya, Indonesia and Borneo.

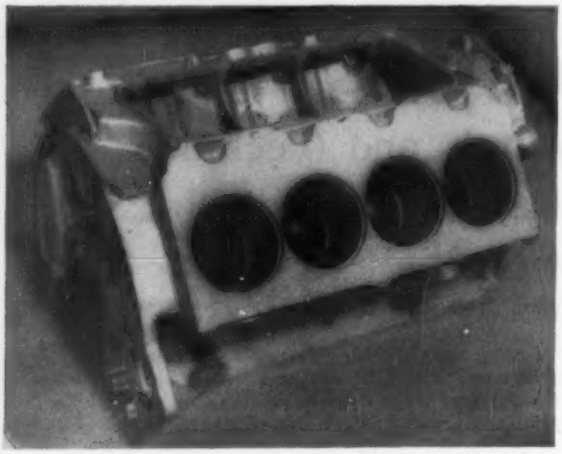
Australia possesses very large reserves of bauxite,[6] but has a *per capita* consumption of aluminium well below that of Western Europe. Expansion of production at Bell Bay has recently been considered, but the construction of entirely new plant may be necessary since a demand of 100,000 tons yearly is envisaged by the 1970's. The existence of vast untapped hydro-electric potentialities and of bauxite reserves leads Starratt[7] to the view that the future of aluminium production lies in the continent of Africa. He sees the possibility that within thirty years half of the world's aluminium will be produced there (but this is dependent upon political stability). A step in this direction is the report that there are plans to build a plant in Guinea[8] to extract 220,000 tons of aluminium yearly, from ore mined locally.

Prain[9] has taken a look at the world's mineral resources and metal reserves, and in any such survey aluminium naturally stands out, both from the point of view of increasing production and usage and as having behind it ample reserves of high grade ore. This author notes that in the decade during which the Institute of Metals was founded aluminium accounted for less than 1% of non-ferrous metal production ; in the 1950's, this share—of a much expanded total output—had increased to 27%, figures being taken by weight, so that by volume the progress is even more remarkable.

Melting and Casting

Reaction between metal and the vessel in which it is contained during melting may be a source of deterioration of both ; this is particularly true of aluminium, which dissolves most metals quite rapidly. Although hardly a tool for the production foundry, levitation melting[10] offers an answer for research or the melting and casting of very pure metals, including aluminium. The charge floats in space due to the action of opposing magnetic fields, and may thus be melted entirely out of contact with any solid material, or even with a gas, since vacuum techniques may be employed.

The tendency for casting production to move towards the pressure die process is a measure of the state of industrialisation and size of market within a country, and quite recently this method has overtaken sand founding in Great Britain in tonnage of castings produced. Smith[11] has reviewed the aluminium alloys used for pressure die-casting, both in this country and the U.S.A., and has drawn attention to some of their less well-known properties, such as those at elevated and sub-zero temperatures. He sighs for an alloy and method of casting which will give consistent bright anodised finishes. The full solution of this problem awaits its Archimedes, and metallurgists no doubt hopefully ponder the matter in their baths ; the cry of



Courtesy of Rolls Royce, Ltd.

Sand casting in alloy LM8-WP—24½ × 20 × 15 in.—forming the V-8 cylinder block for the Rolls-Royce 6·25 litre motor car engine.

" Eureka " is yet to be heard. In a general account of pressure die-casting practice and application, Reed[12] also refers to this problem, and sees the use of vacuum during casting as a possible answer which will repay further investigation. Nomenclature needs attention here; vacuum pressure die-casting seems a contradiction in terms, but vacuum die-casting means quite another process. The Red Queen is no help, and the matter is further complicated by the different meaning assigned in the U.S.A. to the term die-casting.

Woodward and Proffitt[13] have provided a very useful survey of die-casting in Britain, including both pressure and gravity processes. They note that pressure die-casting machines vary in size up to 1,200 tons locking pressure; it is now reported[14] that a Continental machine manufacturer has introduced equipment employing 2,500 short tons locking force, with an injection force of 80 short tons. The company[15] offers thirteen machines ranging from this monster down to a 30 ton pigmy; a 1,500 ton model has been delivered to Russia to produce, in an alloy similar to LM6–M, a tractor bell housing[16] of trimmed weight 24 lb., and an area with sprue and runners of 342 sq. in. Another application of large pressure die-castings is a range of outboard motors[17,18] involving crankcase and twin cylinder block and head to develop 35 m.p.h.; liners are cast-in. Miske[19] has described the die-casting department at a large American foundry, which cuts costs by using continuous melting and conveyorised handling, and has only 400 and 600 ton machines; small castings are produced in multiple cavity dies.

In general, pressure die-casting machines used with aluminium are horizontal, but Barton[20] has pointed out that for certain requirements vertical machines are to be preferred. He cites in particular the casting of large rotor bodies, for which elaborate means of loading and unloading are needed with horizontal equipment. The same author[21] surveys tools for the trimming of die-castings, and notes the advantages of inverted types, which will remove internal flash and also broach short holes. Kessler[22] has considered the fluid dynamics involved when metal is shot into a die, and described the theoretical reasons for such devices as sieves or draw-offs to broaden streams and achieve laminar flow; he also discusses the effect of flow on such factors as homogeneity and surface quality.

Low pressure die-casting, commenced during the last war for the production of aircraft parts, has since been extensively used by Alumasc Ltd.[23] for civilian applications, notably the manufacture of rainwater goods and beer barrels. A recent important development has been the adoption of the process in the U.S.A., particularly for making engine parts for the compact cars that Detroit is now manufacturing to compete—successfully—with imported European models. A number of accounts[24,25,26] have appeared describing the foundry and the process; it uses pressures up to 10 lb./sq. in. to push the molten aluminium alloy into the mould cavity. Yields of 96% are claimed, due to the absence of large risers.

In contrast to low pressure die-casting, ultra high pressure casting: Reiss and Kron[27] subjected alloy A–356, an aluminium-silicon-magnesium alloy similar to LM8, to pressures as high as 100,000 lb./sq. in. during solidification. Grain size and eutectic silicon size were reduced, with benefit to soundness and surface finish, and also to strength and ductility.

The American iron foundry industry has not been slow to recognise the threat to its markets in the automobile industry stemming from increased interest in aluminium alloy engine parts. Sanders[28] considers the merits of the two foundry materials, and indicates that the advantages of aluminium lie in good publicity and education, rather than technical points; one feels, however, that he protests too much, particularly in stating, for instance, that grey iron has thermal conductivity unmatched by aluminium. In contrast, Thomson,[29] representing a large user, considers that aluminium automotive castings are becoming even more attractive to the car manufacturer, but he asks for improved mechanical properties, better wear resistance, and simplified heat treatments, and, of course, lower prices. Automation is one way to reduce costs, and Miske[30] has described its application in an American gravity die foundry. Mechanised charging is followed by automatic pouring into ladles, and thence into gravity dies mounted on a turntable.

Somehow, although recognising all the advantages of casting in metal dies, one is reassured to learn from Brett[31] that the Rolls-Royce V8 aluminium engine is made by sand casting; anything so closely related to mass production as gravity die-casting would hardly do. That the castings are, in the accepted sense of the term, Rolls-Royce, emerges from Brett's account, and this application is a notable milestone in the development of the aluminium motor-car engine. Another important series of sand castings in aluminium alloy is the crankcase for the Deltic compression ignition engines, and Eade and Evans[32] have described in detail how these are made as core assemblies, using a green-sand cope to form the top faces. The largest of these complex castings weighs 565 lb. and all risers incorporate exothermic sleeves which keep the feeder heads liquid for 10–15 minutes.

It is always interesting to learn of techniques used in other lands, and Steele's[33] paper on foundry practice in South Africa is the more welcome because of its novelty. Robinson[34] describes techniques in a small foundry working in iron and copper as well as aluminium alloys; of these last no less than eight are cast, including such

relatively difficult compositions as LM5 and LM11. Much has been written about the gating and risering of castings, and Flemings and Taylor[35,36] have performed a useful service in summarising present views; nevertheless, the design and placement of gates and risers remains one of those functions that makes foundry work an art as well as a branch of technology.

In providing complicated passageways within an aluminium alloy casting, the designer has the choice between using metal tubes which remain *in situ*, or refractory or other cores which are subsequently removed. Elliott and House[37] have provided guidance as to how the decision may be made, and details of core design and support; their article would have been even more valuable, however, with the addition of information as to suitable core materials and methods of removal. Difficulties with blistering when inserts in S.A.P. were cast into aluminium alloy castings were shown by Kessler[38] to be due to traces of oil in the sintered material; by special care in compacting, it is now possible to produce inserts almost completely free of lubricant, which may be cast-in with no blistering troubles.

Control of quality is the constant task of the foundry metallurgist. McNair[39] has surveyed the sand casting process, and considered how variables such as mould material, mould coats, gating and risering and chilling affect quality. The tests used in the foundry are summarised, while a table lists defects, their likely causes and remedies. This is rather reminiscent of the table that appears in instruction books for motor cars, ostensibly to help the amateur to decide why his car will not start; but doubtless McNair's table is much more practical. A Committee of the Institute of British Foundrymen has investigated tests for melt quality[40] including an application of ultrasonics to assess the porosity of D.T.D. bars in alloy LM4–M; the conclusion is that the test works, but the equipment is expensive. As degassers, nitrogen and chlorine each have their advantages and drawbacks; Gottschalk[41] shows that they may be successfully used together; the lion may lie down with the lamb. He finds a 90% N_2, 10% Cl_2 mixture the optimum. More chlorine does not significantly increase the rate of hydrogen removal, and less increases loss of metal in the dross skimmings.

In a general review of melting practice for gravity die-casting, Bonsack[42] stresses the importance of grain refinement; he also refers to the necessity to modify eutectic silicon alloys. Increased interest in alloys containing even more silicon, the hypereutectic group, lends special value to Schneider's[43] description of the addition of sodium phosphide/aluminium powder mixtures to refine the primary silicon, aluminium phosphide being formed *in situ* at the molten metal temperature. An alternative is a red phosphorus/potassium titanium fluoride mixture, which at the same time introduces titanium to refine the matrix of the alloy. Schneider also mentions the claim that aluminium-magnesium alloys containing titanium and boron and treated with carbon tetrachloride have improved properties at elevated temperatures. In an appraisal of the factors contributing to casting quality, Ewijk[44] lists the aluminium alloys popular on the Continent of Europe, and emphasises the importance of close co-operation between designer and foundryman. An old song, but still worth the singing.

Tingley[45] has compared the properties of a fully heat treated aluminium-silicon-magnesium alloy (similar to

Courtesy of Alexander Cardew, Ltd., U.K. Agents for A. Triulzi, s.a.s.

A view of a large pressure die-cast aluminium alloy bell housing for a Russian tractor.

LM8–WP) when cast in moulds of steel, aluminium, graphite, green sand, dry sand and shell. As might be expected from consideration of rates of cooling, bars cast in metal moulds gave better strength and ductility than those cast in the other four mould materials, which gave quite constant results. It has been shown by Spear and Gardner[46] that at slow cooling rates aluminium alloys solidify by forming primary dendrites and by deposition around constituents; solid solution alloys contained more equiaxed crystals and deeply fissured dendrites than alloys with appreciable contents of other phases.

Inclusions in aluminium castings have a variety of sources; they may be oxides, intermetallic compounds, segregated constituents, bits of refractory or have other origins. Smith[47] has listed and described them and included some alarming illustrations of the various types; he also tells us how to avoid these foreign bodies.

Over the past few years, a number of new casting methods have been added to the foundryman's armoury, several of which may be used to produce close-to-form castings. These have been discussed and illustrated by Bailey,[48] who includes a useful table of maximum sizes, attainable tolerances, and as-cast surface finish for each method. One of these procedures is investment casting, and Wood[49] has surveyed progress in this field over the past seven years. Another is shell moulding; Glick[50] has shown that alloy LM4–M when shell moulded has properties and structure similar to those obtained in sand castings. Still others are the CO_2 and plaster processes, as described by Herrmann[51] for the production of tyre moulds.

To the layman, the estimation of the weight of a complicated casting savours at the best of guessing, or at the worst of witchcraft. A most informative article[52] has described just how it is done in American foundries; even when the mystery is removed, the admiration for the skill required remains. Grede[53] has considered the future of cast metals in the U.S.A.; he notes the great increase in production of aluminium alloy castings, and

also that the aluminium industry is adept at technical publicity for its products. Perhaps one of the most important fields for development is in the use of hyper-eutectic aluminium-silicon alloys for the bores of cylinder blocks, and Bates[54] has provided a valuable review of the published information about these materials.

In the pouring of castings and of billets for working, screens are useful to prevent the entry of dross into the mould. Birch and Llewelyn[55] have studied the flow of molten aluminium alloy through screens, and found that it is different from that of water or mercury. They suggest further work to relate flow pattern to metal quality.

Direct casting for wrought production continues to expand. Tessmann[56] has described a horizontal casting unit from which $2\frac{1}{2}$ in. diameter bar is withdrawn and cut up for hot rolling. The continuous casting processes in common use have been reviewed by Fear,[57] and in the same journal issue Angleys[58] describes the recently developed Ugine Venthon process for horizontal casting of round or rectangular sections.

Working

The year has been notable for the addition to the industry's equipment of two new rolling mills. One of these, installed at the Woodgate works of Birmetals, Ltd., is a high-speed Sendzimir cold rolling mill,[59] a 50 in. reversing type capable of producing between 12,000 and 20,000 tons of strip per year in non-heat-treatable alloy, total production varying with finish gauge. An interesting feature of the installation is that it requires for economic operation coils of great length, and these are obtained by joining shorter coils by flash-butt welding, using a welder specially designed and developed for the purpose. At about the same time that it announced its change of name from Northern Aluminium, Alcan Industries, Ltd., opened its 144 in. hot mill and other expanded facilities at Rogerstone.[60,61] Plate well over 10 ft. wide can now be produced, and improvements have also been made to the cold rolling equipment, so that the capacity for sheet and strip will be raised from 50,000 to 70,000 tons a year.

Northern had already installed a large plate stretcher to deal with the product of the new hot mill; a stretcher[62] with a pull of 30×10^6 lb. recently put into use by an American aluminium company is capable of handling a 6 in. aluminium alloy plate up to $13\frac{1}{2}$ ft. wide, and up to 60 ft. long. This enormous machine weighs 3×10^6 lb. Some of us may be forgiven for thinking that the making of an aeroplane in one piece is not so far away. Sutila[63] also makes a claim regarding size; in order to electroform a liner for a high-speed wind tunnel, a hand forging in aluminium alloy was used as a mandrel, and is thought to be the largest ever produced, the ingot being $36\frac{1}{2}$ in. diameter and 78 in. long. The largest forged aluminium alloy rings[64] yet made in this country each have an outside diameter of 76 in. and weigh approximately 1,300 lb.; they will eventually be used in nuclear reactors.

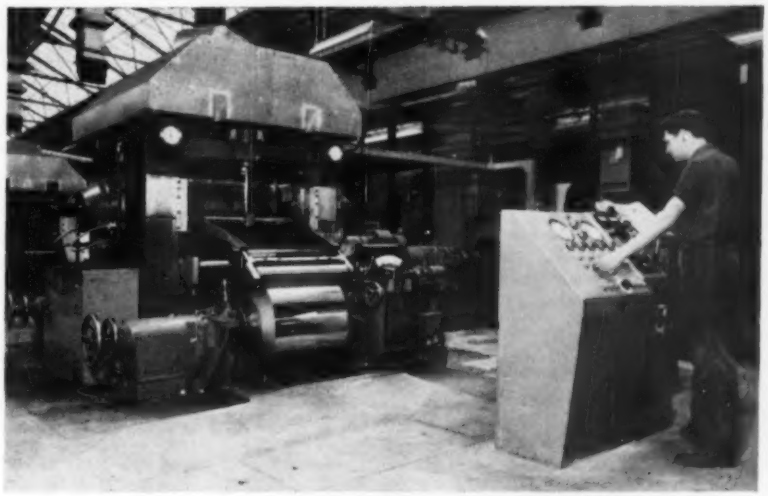
These large forgings incorporated appreciable machining allowances. Forgings requiring little or no machining are termed precision forgings,[65] and their production, advantages and disadvantages have been discussed; the technique is well advanced for the light metals. In the U.S.A., very large forging presses are available for making of large airframe sections close-to-form; the drawback is evidently in the cost of the tooling. Writing on the cold deformation of metals, Pugh[66] considers cold forging of aluminium amongst other metals; he finds that the impact forging stress for identical cylinders of pure aluminium varies by $\pm 4\frac{1}{2}\%$, as against $\pm 11\%$ for lead. The stress required to deform aluminium lies between that for lead and that for copper, as might have been expected. Quadt[67] has described the precision cold extrusion of a number of metals and noted that aluminium is particularly suited to this process; paradoxically enough, the high strength alloys present fewer difficulties than the softer non-heat-treatable materials, and offer transverse properties equal to those in the longitudinal direction.

Using a cam plastometer, Arnold and Parker[68] have determined the resistance to compressive deformation at various strain rates and temperatures of pure aluminium and representative non-heat-treatable and heat-treatable alloys. Considerable variation is shown, and some of the data are used to plan pass sequences in a schedule for hot rolling an aluminium-magnesium-silicon alloy in order to attain a high degree of uniformity of loading and a low maximum. James[69] has considered in some detail the measurement of grain size in rolled metals, including aluminium, and its effect on various properties. He recommends that grain size limits be introduced into specifications, although recognising that this will be opposed both by production staffs and those who would have to undertake the far from simple task of measurement. By deforming aluminium discs between profiled dies, using various lubricants, Butler[70] has shown that a semi-continuous lubricant film can easily be trapped between tool and metal, resulting in a matt, non-reflective surface, instead of the bright appearance demanded in strip rolling and other metal working operations. Schey,[71] investigating the cold rolling of pure aluminium, aluminium-manganese, aluminium-magnesium and aluminium-copper-magnesium alloys, considers that variations in coefficient of friction are related to the ease with which the material being rolled welds to the steel roll surface; the more highly alloyed materials have therefore lower frictional coefficients, and boundary additions are more effective in reducing friction on pure aluminium and its common alloys than on the higher alloys. In an attempt to arrive at a specification for a satisfactory cold rolling lubricant for aluminium alloys, Gumminski and Willis[72] have devised tests for "reduction capacity" (possible reduction per pass), staining, surface finish and stability. Certain organic compounds rate high in all tests, but unfortunately are much too expensive for practical use; however, some base oils with additions approach the standard desired. Yokote and Nomura[73] compared theoretical calculations with practical experience in foil rolling, and found that while for three passes the test data agreed with the theory, at the fourth and fifth the roll pressures measured were well below those calculated, possibly due to softening of the metal by heat generated in rolling.

It is tempting to say that explosive forming has arrived on the metal working scene with all the impact of a block-buster. Certainly since it was first announced it has attracted great attention. Zernow[74] has discussed principles and practice; he surprises us by the information that it is an old technique, patented before 1900. Its chief advantages are low capital cost, large sizes of workpiece, and quick prototype fabrication. In Canada aircraft companies are using explosive forming for various

Courtesy of Venesta Foils, Ltd.

A four-high foil rolling mill brought into operation during 1960.



materials, and have applied the process to joining unlike metals, including, according to Tardif,[75] brass to aluminium. Bertossa[76] has described applications of explosive forming and chemical milling used in the U.S.A. This is described as a special report from the West; it would surely be topical if the explosions could follow each other rapidly in batches of six.

Work still continues in the search for a reliable test of deep-drawing quality. Whitton and Mears[77] have investigated the control of testing conditions necessary in the Swift cupping tests; they found that aluminium required close tolerances on blank size, and that punch and die surface quality was the most difficult factor to control. An hydraulic bulge tester is used by Lambert[78] and his co-workers, and they conclude that for brass, copper, steel and aluminium it has fine discriminatory powers and reliability. Fields[79] has compared methods of determining drawability, and considers that the Swift test will probably remain a laboratory tool for assessing simpler tests devoted to plant quality control.

Discussing the stretch-forming operation, Wallace[80] considers especially stress distribution and springback in various metals, including aluminium. He also describes laboratory tests using ice lubrication, but these were not carried out with aluminium. Metal spinning[81] is an ancient craft, but it still has many advantages, particularly for large size work and small quantities; a recent general account states that the limit of thickness for spinning aluminium is about $\frac{1}{4}$ in., and that tools of aluminium bronze give the best finish. No doubt care must be taken to ensure that no material from the tool becomes embedded in the surface of the workpiece.

Barlow[82] has continued his valuable work in determining working bend radii, this time for sections and rectangular tubes. He indicates the mode of failure on bending in section of various shapes and provides tables of bend radii for a number of sections in almost the complete range of alloys in B.S. 1476, covering bending with the legs of sections in various aspects.

Garden furniture and television aerials have an important point in common; they are made from aluminium alloy tube produced by forming and high frequency resistance welding, as has been described in a recent article.[83] Pipe made by conventional means is flattened into ribbons by cold rolling and becomes "Strubing"[84]; it may be inflated in the field when required by hydraulic pressure, air pressure or mechanical means.

METALLURGIA's[85] annual review of heat treatment furnace installations serves as a useful indication of the extent of industrial investment in this field. It includes two coil annealing furnaces for aluminium each of which will take a load of 250,000 lb. stacked to a height of 150 in. Three twin-chamber electric batch furnaces[86] for aluminium wire have been installed in South Wales; they may be used for solution treatment, precipitation treatment and annealing. Aluminised steel baffle plates are incorporated to separate the electric heating elements from the heating chambers, thus preventing direct radiation on to the charge. High frequency resistance heating[87] is applied to the annealing of aluminium wire in an annealer working on 450,000 c./s. current passed directly through the wire at several hundred ampères; the process is claimed to provide faster annealing than any other method. An American aircraft company has solved the problem of distortion in quenching thin strip[88] by the use of spacer springs to restrain the coils and prevent metal-to-metal contact.

(to be continued)

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Correction

Development at Alcan's Rogerstone Plant

Our attention has been drawn to the following errors of fact in the description of the 144 in. hot mill at Rogerstone which appeared in our November, 1960, issue.

In paragraph 4 in the first column of page 204 it is stated that the fourteen split conical rollers on the entry table are of cast iron: they are in fact of forged steel.

The finished weight of the mill housings is 165 tons, not 163 tons, as stated in paragraph 2 in the second column of the same page, and their dimensions are 33 ft. 6 in. long × 15 ft. 6 in. wide, not 33 ft. long × 15 ft. wide overall: the cross-sectional post area is 1,200 sq. in., not 1,420 sq. in. as stated.

The last five lines of paragraph 1 in the first column of page 205 should read: ". . . beams, pivoted and hydraulically balanced at both motor end and mill end. The bottom spindle, between the jack shaft and the bottom work roll, is also set in hydraulically balanced carrier bearings at each end."

Metal Treatment Chemicals

To the three divisions of Diversey (U.K.) Ltd., operating in the United Kingdom—food handling and processing industries, catering industry, and agricultural industry—has been added a fourth, the metal industries division, which will handle the company's range of materials for the preparation of metals prior to further processing. These compounds are used in the pretreatment of aluminium and aluminium alloys, particularly as a preparation for spot welding, anodising, conversion coating, electroplating, lacquering and vitreous enamelling.

University College of Swansea Appeal

Gifts of £20,000 from the Consolidated Zinc Corporation and £10,000 from the Mayor and Corporation of the County Borough of Swansea enable the University College of Swansea to announce that the Appeal Fund launched last autumn now stands at nearly £320,000. The British Aluminium Co., Ltd., which includes Reynolds T.I. Aluminium, Ltd., and Aluminium Wire and Cable Co., Ltd., has contributed £10,000, and other recent gifts to the Fund are £7,000 from Duports, Ltd., per Briton Ferry Steel Co., Ltd.; £3,500 from Marks & Spencers, Ltd.; £1,750 from Lloyds Bank, Ltd.; and £1,000 each from Ford Motor Co., Ltd., F. W. Woolworth, Ltd., the Viscose Group of Companies, Swansea, the Baglan Bay Rolling Mills, Ltd., and the Midland Bank, Ltd. The Swansea Departmental store of David Evans & Co., Ltd., has given over £1,100 under covenant. The County Borough of Merthyr Tydfil has given £100 to the College from its Welsh Church Act Funds and other local authorities also have indicated their intention to support the Appeal.

Developments in the Forming of Aluminium Sheet

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Aluminium has shown itself fully capable of forming by any means yet devised, although with the heat treatable alloys it is preferable that forming operations should be carried out after solution treatment and before the final precipitation hardening treatment is applied. In this present survey of developments in this field, reference is made to metal spinning, deep-drawing, pressing, high-energy forming and stretch-forming.

THE forming of sheet metals into complex shapes has been for most of its history an art depending upon the skill and strength of true craftsmen. With the machine age, this situation began to change, the craftsman's skill and ingenuity becoming concentrated on the development of tools and mechanisms rather than on finished components. During the change from hand to machine working the need for improvement and consistency of metal quality became obvious, the techniques devised for working setting the pace in the search. Aluminium was of course unknown to the early hand workers and did not appear on the scene until the present machine age was well advanced, but it has since shown itself fully capable of forming by any means yet devised.

Metal Spinning

It is on record that this process for shaping metals was recognised as a distinct art in the 18th century when European artisans formed their own trade guild. The basic metal spinning process employs a simple lathe and the sheet material is worked round the rotating former by manual pressure with an appropriate tool, usually made of hard wood, levered against a fulcrum on the lathe bed. No sensible change in metal thickness is intended to result, but the success of the operation depends upon the skill of the operator. In view of its low yield strength, pure aluminium continues to be extensively used for the production of components by spinning.

The process is not, however, confined to pure aluminium; all the commercial sheet alloys can be spun, though only limited forming should be considered on alloys in the heat treated conditions T, W or WP*. These alloys are usually spun immediately after solution treatment, while still relatively soft and ductile. Where heat treatment equipment is not available at the spinner's works, annealed material is worked to approximately finished size and given a sizing operation by spinning after solution treatment.

For hand spinning, the maximum thickness of aluminium which can normally be considered is $\frac{1}{4}$ in.,[1] and although the tolerances depend upon a number of factors such as size of spinning, gauge and type of material, and type of tools, the following may be considered typical :—

Diameter	*Tolerance on Diameter*
Up to 24 in.	$\pm\frac{1}{64}$ in. to $\pm\frac{1}{32}$ in.
24 in. to 48 in.	$\pm\frac{1}{32}$ in. to $\pm\frac{1}{16}$ in.
48 in. and above	$\pm\frac{1}{16}$ in. to $\pm\frac{1}{8}$ in.

There are many applications for which such tolerances are unacceptable, and improved accuracy has followed the introduction of power spinning lathes. In these machines the headstock is usually fitted with roller bearings, and the hand tools are replaced by rollers which are hydraulically controlled. Dimensional inaccuracies due to wear on the rotating parts of the machine have therefore been eliminated, and the

Courtesy of G. A. Harvey & Co. (London), Ltd.

Pressure vessel ends, 10 ft. in diameter, produced by spinning from $1\frac{3}{8}$ in. thick aluminium-magnesium alloy NP5/6. These are believed to be the largest spun ends produced in this country, the blank being produced by butt welding two plates to form a flat disc 12 ft. in diameter.

* T—Solution treated; no precipitation treatment required.
W—Solution treated; will respond to precipitation treatment.
WP—Solution treated and precipitation treated.

Courtesy of Corfield-Sigg, Ltd.

Examples of catering ware in commercially pure aluminium produced by flowforming.

operator is relieved of the fatigue associated with hand spinning and can expend his energies on maintaining consistency in operation. In contrast to hand spinning it is claimed that dimensional tolerances of 0·005–0·010 in. are reasonable for power spinning.

As previously stated, there is no intention to reduce the material thickness from that of the original blank, although some ironing is necessary to offset the thickening which occurs as the flat sheet is drawn up into shape. For this reason, at least, it is simpler to produce a conical shape than a cylindrical one. The newer process of flowforming (also known as flo-turning, hydrospinning and stretch planishing) in which different requirements apply with respect to the size and thickness of blank in relation to the dimensions of the final part, is also more suited to the production of cones than of cylinders.[2,3]

For this process machines are extremely robust; large diameter headstock bearings are provided to withstand the high radial and axial loads, the tailstock spindle is operated by hydraulic power, and the forming rolls are fed and traversed hydraulically. For the production of a conical component, the blank diameter approximates to the major diameter of the cone and the component is produced on a metal chuck or mandrel by a continuous reduction in gauge of the wall by pressure from the rollers. In such a component, therefore, the base thickness is always greater than the thickness of the curved surfaces, but the process does facilitate the production of components with integral circumferential stiffeners, etc. Only limited applications of flowforming of aluminium have arisen, but it is stated that the material requirements of this process are a good degree of strength and ductility and a reasonable increment between proof stress and tensile strength. Most wrought aluminium grades are therefore suitable, the heat treatable alloys requiring solution treatment immediately prior to forming.

Deep-Drawing and Pressing

The deep-drawing process consists essentially of forcing a punch through a ring die, drawing sheet material which has been placed over the die. It makes many demands upon the material, since the metal is bent over the die edge and compressed circumferentially as the blank diameter is progressively reduced. The material in contact with the end of the punch is pulling the sheet through the die, and hence high tensile stresses are developed in the material touching the wall of the punch. As drawing proceeds the remaining blank will tend to corrugate as it is drawn towards the die, and this wrinkling is avoided by placing a restraining compressive force against the die plate. There will, however, be a tendency for the material thickness to increase due to the circumferential compression, and this may be overcome by ironing, i.e. limiting the clearance between punch and die. These factors obviously lead to further tensile stresses in the cup as it is drawn.

For deep-drawing, therefore, suitable material requires not only adequate capacity for bending, stretching, etc., but also ability to withstand high tensile stresses. The highest elongation values can be obtained in fully annealed aluminium, but harder metal is commonly used to meet the tensile loading requirements of the process. Nevertheless, careful control is required on blank holder pressures, punch-die clearances, and lubrication in order to maintain a low order of tensile loading. Since the high tensile stresses occur in the central region of the blank and the maximum ductility requirements are towards the periphery, a blank of varying hardness offers an advantage, and differentially

Courtesy of Swift's of Scarborough, Ltd.

Ten gallon milk can in aluminium-magnesium-silicon alloy fully heat treated after forming. The body of this can is produced in one piece by flowforming a deep drawn cylinder.

annealed blanks are produced which enable greater reductions—up to 58%—in one draw. The width of the annealed zone required obviously varies according to the configuration of the component, and these blanks are therefore produced in co-operation with individual users to meet their specific requirements.

One distinct disadvantage of the deep-drawing process is the high cost of the tools, which renders it uneconomic for small quantities. Whilst for long runs hardened steel or inoculated cast iron tools are required with a highly polished finish, zinc-base alloys can be used for smaller runs, and for simple smooth and shallow shapes, tools of laminated wood have proved suitable for quantities up to 3,000.[4] However, the use of these materials, although they are easier to work than steel, still requires accurate matching of the punch and die, and this operation is still expensive in terms of labour and plant time, since press trials are usually necessary to ascertain the need for modification. To overcome this objection the use of a single tool, the punch, has been considered, the die being replaced by a pad of rubber. As introduced before the war, and generally known as the Guerin process, deep-drawing was not possible, but extensive use of this process has been made for relatively shallow pressing. The process employs a punch having the contour of the inner face of the final component, and this is placed on the press table whilst the upper die consists of a laminated rubber pad, contained in a steel box to prevent horizontal displacement of the rubber. The aluminium blank is placed on the punch and the press platens are brought together. During and since the war, deep-drawing processes employing rubber pads in place of a die have been developed. The Marform and Hydroform processes are two such developments.

Example of motor car door assembled from pressings in aluminium-magnesium alloy.

The Marform process, developed by the Glenn L. Martin Co., uses a pressure plate of a dimension per-

FEATURES OF SOME FORMING PROCESSES FOR ALUMINIUM SHEET

Process	Shapes Produced	Size Limitations	Tools	General
Hand Spinning	Essentially confined to components on a circular base. Conical and parabolic shapes more readily produced than plain cylinders.	Usually employed for items up to ½ in. thick and 2 ft. diameter but machines available have produced items well in excess of this diameter.	Chucks generally produced from wood, quality of which would depend upon thickness of spinning and quantity involved.	Process used for batch quantities of unity to several thousands. Operation time may be greatest single component of total cost.
Power Spinning	As above.	Can accept considerably greater material thicknesses. Items up to 10 ft. diameter have been produced by this method.	Metal mandrels and forming rolls usually required, material selection dependent upon component dimensions and batch quantity.	Provides greater dimensional accuracy and higher output rates than hand spinning.
Flow-forming	As above. Components with flanges thicker than general wall readily produced.	Base thickness greater than wall which may be stepped in thickness as required.	Metal mandrels and forming rolls.	Good dimensional accuracy possible. Process requires blank of greater thickness than product, with diameter equivalent.
Deep Drawing and Pressing	Cylindrical, rectangular or similar shapes. Conical and parabolic shapes less readily produced.	Dependent on press stroke and capacity and platen area. Deep drawn components generally within 3 ft. diameter circle, but area is often exceeded in shallow pressing.	Steel punch and die where large quantities or high loads involved. Other metals and some plastics can be used for small runs.	Good dimensional accuracy possible. When produced in single draw, low operation time obtains but method using drop hammer may result in increased operation time with saving in tool cost.
Guerin, Marform and Hydroform Processes	Cylindrical, rectangular or similar shapes (Guerin restricted to shallow forms). Conical and parabolic shapes present less difficulties than when deep drawing in rigid dies and undercuts in punch are also practicable.	As above.	Punch only required. Material employed may be steel or softer metals or some plastics dependent upon quantity and press loadings involved.	Dimensional accuracy comparable with deep drawing and pressing in rigid tools. Operation time higher but fewer operations may be necessary and tool cost will be lower.
Explosive Forming	Any shape which may be extracted from enveloping die.	Size not limited by machine capacities, etc., practical limitation only in respect of size of die and blank which can be provided.	Outer die only required. Die materials depending on form may be plaster, concrete, plastics, metal, etc.	Operation setting up time generally extended. Process results in extremely high fidelity in reproduction of die surface contours and permits greater deformation in one operation than other processes.
Stretch Forming	Generally panels of simple or compound curvature. Severe or re-entrant curvature possible but not desirable.	Large panels up to 6 ft. × 10 ft. thicknesses generally up to about 14 S.W.G. in current machines.	Stretch blocks of wood, plaster, concrete, plastics, metal, etc.	Process replaces hand panel beating in forms where large areas are concerned. Heat treated alloys commonly formed in solution treated and naturally aged condition.

Courtesy of Saro (Anglesey), Ltd.

Light runabout, the hull of which is produced from two components made in aluminium-magnesium-silicon alloy by stretch forming.

mitting it to enter the rubber container. This plate is controlled by hydraulic pressure, independent of the press system, and at the start of the operation is in a position level with the end of the punch. As the operation proceeds the rubber is forced against the blank and the pressure plate sinks in accordance with the degree of unbalance between the two systems. The pressure in the pressure plate system can be preset and automatically varied throughout the operation. The material over the punch is supported throughout the operation by the rubber bed, and at the conclusion of the draw, the press is opened, removing the punch, complete with drawn part, from the rubber pad. The pressure is now increased in the blank holder system, returning the blank holder to its original position, thereby stripping the component from the punch.

In the Hydroform process the rubber pad is replaced by hydraulic pressure supporting a rubber diaphragm. The main ram is usually in the base of the press and at the start of the operation the tip of the punch is level with the bed plate. The blank is placed on the press bed and the press head is lowered and locked in position. This head contains a cavity of sufficient depth to accommodate the maximum stroke of the ram, the cavity being sealed at the lower end by a rubber diaphragm. While the press is open the cavity is at atmospheric pressure, but positive pressure is applied when the press is closed. The pressure applied depends upon the component configuration and the blank material properties and thickness. The punch is then raised, thus forming the component against the rubber diaphragm. This rubber sheet also acts as a blank holder, and it will be appreciated that when the punch enters the pressure cavity the pressure will be increased as the volume is decreased. This can be adjusted by a system of bleed valves and a preset pressure sequence can be provided. After the completion of the draw the chamber pressure is reduced, the chamber removed and finally, the punch withdrawn to permit the extraction of the finished components.

Apart from the reduced tooling costs these processes permit greater draws than the orthodox process and thus fewer operations for a given part, although the operating time for each operation is somewhat greater (60–120 per hour). The processes also facilitate the deep-drawing of components with undercuts since the " die " is flexible. Extensive experience of the production of aluminium components by these processes has been gained by aircraft manufacturers over the last fifteen years, but the processes have not yet achieved wide usage elsewhere.

A process developed in Sweden[5] utilises an oil-filled rubber punch and a rigid female die. At rest the punch has a flat bottom, but takes up the required shape of the female die as pressing proceeds. This process lends itself to the final forming to intricate form and close tolerances of cups which have been deep-drawn by orthodox methods.

Drawing has also been undertaken on thin heat treated aluminium alloy sheet by the use of hydraulic pressure without the aid of a rubber diaphragm[6]. The press ram merely applies pressure to the material surrounding the die apertures, and oil is applied through vents in an aluminium selector plate from a line pressure of 1,000 lb./sq. in. to produce the component configuration. The main ram pressure must be sufficient to prevent the forming oil from escaping, but any oil residues from the operation serve to provide lubrication for the next blank.

For relatively short runs, where low tool costs are an essential but a longer operating time can be tolerated, drop hammers are employed. The component is usually produced in a number of blows, the depth of each succeeding blow being controlled by a series of plywood pressure plates which are reduced in number as the operation proceeds. This process is often used as a final ironing operation on components produced on power presses where avoidance of wrinkling and puckering is difficult.

High-Energy Forming

Considerable interest has been shown in recent years in the developments of high-energy processes. Of these processes, methods using high explosives appear to have received most attention[7–15], although the principle is not particularly modern, patents being issued before 1900. The sheet forming processes used have been classified in two groups, those using low explosives or propellant powder gases contained in closed dies, so that they expand against the work piece, and those using high explosives with an intermediate medium such as water, oil, plastics, talcum powder, paper, clay, etc. The high explosives mentioned include Cyclonite, Primacord, Cordtex, PETN and RDX.

When considering the suitability of a given explosive the duration of the force obtainable is an important factor. Whilst pressures obtained from low explosives are of milliseconds duration, those from high explosives are of microseconds duration. The tools employed have been made from steel, aluminium, zinc alloys, steel-backed epoxy resins, concrete and even plaster-of-paris for short runs. Air must be excluded from the cavity between the blank and the die form to obtain components of accurate dimensions, and as the slightest surface imperfections on the tool may be mirrored on the finished component, a high finish is required. High-energy forming methods appear to produce a more uniform movement of the blank, there is less thinning than obtained with orthodox press equipment, and the

whole surface of the component appears to be work hardened by compression, an example quoted in this context being produced from 99·9% pure aluminium.[7,10] Other advantages claimed for explosive forming techniques are virtual elimination of spring-back, greater degree of forming in one operation than by orthodox press methods, and absence of limitations on component size. Whilst explosive forming can be costly and unsafe when carried out on a haphazard trial-and-error basis, it is stated that the process can be carried out under conditions where operator hazards are no greater than in many other industrial processes, and the noise of the explosion, being absorbed somewhat by the buffer medium and the die, would not normally interfere with machine shop operations.

Two further methods of providing energy for high-velocity forming have received some attention in the last few years. An equipment known as Hi-Vo-Pac[16] has been developed to provide electrical explosions in water in closed dies. In the earlier models voltages of 14,000–22,000 were involved, but on development the voltage has been reduced to 4,000 volts and a capacitor bank of 1,200 micro-farads is charged and discharged to tungsten electrodes placed in appropriate positions in the die. Discharge of the capacitors vaporises the electrodes, increasing the original volume by more than 25,000 times. This produces a shock wave in the water and forms the part. The process is stated to be safe for operation by non-technical personnel, and the capacitor unit can be charged and discharged either manually or automatically in six seconds.

Another method of providing high energy at rates comparable with low explosives is known as the Dynapak[17]. This equipment operates a ram at velocities exceeding 2,000 ft./sec. with an energy of 1,500,000 ft.lb. The operating mechanism consists of a cylinder incorporating an orifice plate at the top of the ram stroke. The piston is returned to the orifice plate position by a low gas pressure constantly maintained below the piston. The orifice plate seals off all but a small area of the piston surface, and the chamber above the orifice plate is filled with high pressure gas. A slight increase in this pressure breaks the seal between the piston and the orifice plate, creating a condition of severe unbalance and providing a high velocity movement to the ram. This equipment, unlike explosive forming, has limitations to the component size which can be handled, but operational cycles of only 30 seconds can be maintained and the velocities can be controlled to within 1–2 ft./sec.

Stretch-Forming

This process has been in operation for some twenty years and has been extensively used for the forming of aluminium skin panels for aircraft. One machine described[18] has an overall height of 18 ft., with a maximum pull of 180 tons, and can handle panels up to 72 in. wide. In this process the sheet material is gripped at both ends, formed around form tools of wood, plastics or zinc alloy, and given a controlled stretch of approximately 1%. This can be satisfactorily undertaken in forms where severe bends are not involved in high tensile aluminium alloy sheet in the solution treated condition (B.S.L72 or B.S.1470–HS15W) which can then be precipitation treated to obtain the full strength properties of the material.

The process is wasteful in material since the sheet held in the grips must be discarded, but it nevertheless often represents the only method of producing batch quantities of a large component in one piece. Unless adequate lubrication is given to the form tools, there is also the possibility of material loss by fracture due to local overstressing, and a recent article[19] discusses the value of melting ice as a lubricant for this process.

A development of the stretch-forming process known as Androforming[20,21], has the advantage that individual form tools are not employed, the machine incorporating an adjustable standard tool set. The component is pulled through a forming sequence of three stages providing controlled differential stretching and facilitates the production of compound curved panels in heat treated aluminium alloys in thicknesses up to $\frac{3}{16}$ in., with material up to 10 ft. wide and 48 ft. long.

Material and Process Development

A number of conferences in recent years have provided some interesting reports. This year (1960) saw an International Colloquium on the Forming of Sheet Metals in Paris. Many of the papers discussed at this meeting were concerned with the properties of materials and provided some indication of the lines of thought being pursued in research establishments in the contributing countries. The importance of tool finish when deep-drawing aluminium was emphasised in one paper[22] whilst another[23] discussed the results of a number of types of tests used in evaluating the drawability of aluminium. The British delegation to this meeting was supported by the Institute of Sheet Metal Engineering, which has organised a British Deep Drawing Research Group in which the aluminium industry is well represented. The Institute of Production Engineers held a conference in the autumn on Manipulation of Metals, which, of course, included processes for the working of sheet aluminium.

In the previous year the Eleventh Western Metal Congress and Exposition in Los Angeles[7] included a session at which some twenty experts expressed their views on explosive forming, and this process was also included in the papers presented at The Institute of

Courtesy of De Havilland Aircraft Co., Ltd.

Stretch forming in progress. Material being formed is an alloy similar to HC15 in the solution treated condition.

Courtesy of Grundy (Teddington), Ltd.

Beer cask produced from aluminium-magnesium-silicon alloy sheet and sections, fully heat treated after assembly.

Sheet Metal Engineering Annual Conference and Exhibition.

One of the advantages of high-energy forming methods is shown in a recent paper publishing the results of tensile tests at speeds somewhat higher than those normally employed[24]. Although in this work the rates of strain were only about 80 in./in./sec., compared with strain rates up to 25,000 in./in./sec. applicable to high explosive forming, it is noticeable that these moderately increased strain rates result in higher elongation values than are found on normal static testing. The materials tested included annealed aluminium-magnesium alloys, and annealed and heat treated aluminium-magnesium-silicon and aluminium-zinc-magnesium alloys. Whilst knowledge of the resistance of materials to stresses at high velocities is vital for present technological developments, the Paris conference clearly indicated that our knowledge of material properties desirable for conventional deep-drawing is by no means complete, and research on various aspects of drawability must continue.

An example of the application of this field of research[25,26] is the general availability of aluminium-magnesium alloy sheet and strip which can be readily formed without the development of stretcher-strain markings, a blemish which previously had been commonly seen on pressings in these materials. Research on the improvement of aluminium alloys for forming is being actively pursued, and it is suggested that attention should be directed towards the drawing properties of the high strength heat treatable alloys. Whilst certain of these are quite suitable for forming, elimination of their present natural age hardening characteristics (without prejudice to the properties now obtained after precipitation treatments) would be of considerable benefit to production departments.

Applications

The superior thermal conductivity, light weight and corrosion resistance of aluminium ensure the retention of its well established popularity as a material for domestic cooking utensils. Such items as saucepans are readily produced as spun or deep drawn components, and thick bottom components for electric hot plate use can be produced in a number of ways, including deep-drawing and ironing, power spinning or flow-forming, or by a combination of these processes.

In the packaging field, drawn aluminium containers are extensively used in parts of the continent, but although aluminium beer cans are at present too expensive for general consumer use in this country, the ease of handling and forming aluminium has led to its use for bottle crowns. Aluminium beer casks have been in use for several years and the wrought forms of these products are produced by several methods, including deep drawing and power spinning. These are generally produced from heat treatable aluminium-magnesium-silicon alloy clad with aluminium on the inner surface.

B.S.3291/1960—" Specification for 10 Gallon Aluminium Alloy Milk Can and Lid "—specifies a number of aluminium materials suitable for transporting milk, and a number of methods of production are employed for this development. In this country they are mainly produced from aluminium-magnesium-silicon alloy, fully heat treated after assembly, and may be fabricated by welding from a number of drawn and pressed units, or by flowforming the complete form (including the neck) from a deep drawn shell.

The rubber forming methods developed for producing components for the aircraft industry are being used on commercial applications, and whilst it is unlikely that a similar extension can be expected to the uses of explosive forming, the stretch-forming process is being used for non-military applications, for example in the forming of a power boat hull. The extension of the use of aluminium in transport applications will probably result in the further use of this process in place of the panel beating methods necessary in prototype or small quantity production.

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Vitreous Enamelling in Open Fired Furnaces*

Interim Report on West Midlands Investigation

THE vitreous enamelling industry is by tradition a large consumer of gas, which is widely used in indirectly heated furnaces, in which heating is effected through refractory muffle walls. Below are presented the interim findings of an investigation carried out in the Midlands into the application of a form of direct heating to compete with oil which provides a cheaper fuel service and electricity which can be, and is, applied directly.

The aim of the investigation was to examine the possibility of firing batch-type enamelling furnaces directly with town gas of the normal sulphur content, i.e. 20–25 grains/100 cu. ft. The design is based upon the idea of maintaining preheated air round the work in a direct gas fired furnace, and is covered by Provisional Patent No. 21815/58. Fig. 1 shows the general layout of the experimental furnace as modified for methods 4 and 5 (see below). The provisional trials were carried out in co-operation with a firm of vitreous enamellers and a prototype furnace was installed at their premises and used for the enamelling of suitable samples of steel sheets with colours known to be sensitive to sulphur attack. The enamelling company prepared all the plates and were consulted as to their firing; they also inspected all the finished work.

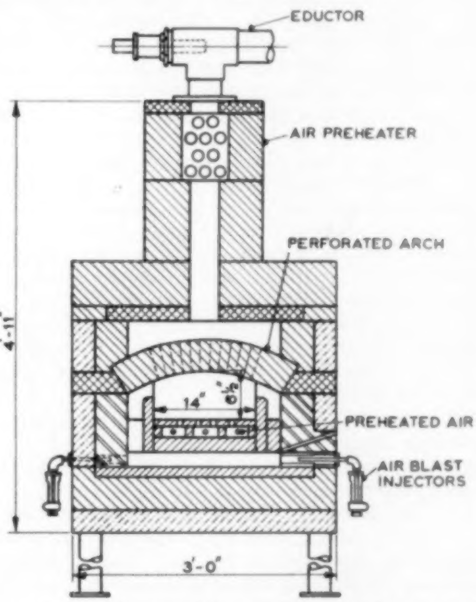

Fig. 1—General layout of the experimental furnace modified for methods 4 and 5.

Operation of Prototype Furnace

The prototype furnace has a hearth area 18 in. by 14 in. underfired by five air-blast tunnel burners, having Keith Blackman injectors operating from the gas supply at atmospheric pressure. The hearth has $2\frac{1}{2}$ in. side tiles and the products of combustion are evacuated through a perforated furnace roof arch, the crown of which is 9 in. above hearth level. The perforations are uniformly-disposed $\frac{5}{16}$ in. diameter holes totalling 168. The hot products of combustion then pass through a metallic recuperator and are evacuated through an eductor. Air heated in the recuperator can be fed into tubes located in the vicinity of the hearth, and in later tests was arranged to be discharged under a perforated platform supporting the work and supported by the original hearth so as to form a false hearth. The practical problem involved is that of creating at hearth level in the furnace a local dilution of products of combustion to surround the work. In these series of preliminary tests five methods were tried.

Method 1.—As shown in the drawing, three sillimanite tubes extending the length of the hearth and drilled with $\frac{1}{16}$ in. diameter holes were used to force air at approximately 300° C. from the recuperator downwards on to the work. It was found that the impingement of the relatively cool air on to work at 860° C. interfered with the fusion of the enamel locally, giving poor results. It was observed that where the concentration of carbon dioxide in the proximity of the work was 1% or less, there seemed to be no adverse sulphur effect on the gloss.

Method 2—Two methods of "cyclic" working were tried :

(*a*) The furnace chamber was purged of products by means of air from the air blast burners, the gas to these burners being turned off. After thirty seconds purging the concentration of carbon dioxide was reduced from 10·5% to about 1·5%. It was then possible to enamel satisfactorily with very little fall in furnace temperature.

(*b*) The furnace chamber was purged of products of combustion by means of the eductor after the air and gas to the burners had been shut off. In this case the carbon dioxide concentration fell from 10·5% to 1·1% in about thirty seconds. There was also a fall of 50° C. from 980°–930° C. in furnace temperature during one enamelling cycle.

Method 3—Continuous firing was maintained and the eductor so adjusted as to keep the carbon dioxide concentration at hearth level at less than 1%. A series of eductor settings was determined corresponding to pre-

* Reproduced from Report No. 732/60 of the Industrial Gas Development Committee of the Gas Council (information supplied by the West Midlands Gas Board).

TABLE I.—RESULTS OF USING METHOD 3

Burner Air Pressure (in. w.g.)	Eductor Air Pressure, (in. w.g.)	Air Introduced			Eductor Alone	
		Volume (cu. ft./hr.)	CO_2 in Furnace (%)	Furnace Pressure (in. w.g.)	CO_2 in Furnace, (%)	Furnace Pressure (in. w.g.)
1·7	0·4	540	5·3	+0·02	1·2	−0·01
2·0	0·6	750	4·0	+0·02	0·7	−0·01
2·5	0·8	620	3·8	+0·01	0·6	−0·01
3·0	1·0	650	1·3	0	0·2	−0·005

determined burner air pressure settings in order to maintain the temperature and yet keep the carbon dioxide below unity.

Method 4—Although it was possible to obtain satisfactory purging results by using method 3, it was apparent that these conditions would not obtain in a large furnace, as in the tests carried out much extraneous ventillation was induced through the door etc. A false perforated hearth was therefore built above the existing hearth, so arranged that air could enter into the space between the true and false hearth by means of bottom vents. With this modification it was found that when air was introduced under pressure beneath the false hearth it was necessary to arrange for the eductor to extract products and underhearth air so as to prevent any pressure build-up in the furnace, in order to achieve low carbon dioxide concentration at the hearth. The alternative was to use the eductor alone to induce air entrainment through the bottom vents, in which case there was always a negative pressure in the furnace. Table I shows a typical set of results.

Method 5—With a large enamelling furnace the use of an eductor would be inadmissible and a hot gas fan seemed undesirable. Further attempts were made, therefore, to utilise ventilation by hot air under pressure. The eductor was removed, the bottom vents beneath the porous hearth sealed, and the preheated air admitted through three ⅜-in. open-ended tubes having individual control so as to discharge into the space beneath the false hearth. A number of tests were then carried out and it was found that a suitable atmosphere could be obtained surrounding the work, subject to the admission of the correct amount of air. Table II shows typical conditions in a furnace being brought to enamelling temperature.

Whichever method is used, the economic considerations of introducing extraneous air are essentially the same. With the experimental furnace the maintenance gas rate to hold the furnace at the required temperature when used as a standard oven furnace amounted to 108 cu. ft./hr. In this case the carbon dioxide concentration in the flue gases was 11·4% with a furnace temperature 980° C., burner air pressure 12 in. w.g., without eductor or forced air, and having bottom vents closed and flue damper open. The total calculated heat requirement when using extraneously blown air under the hearth at the rate of 450 cu. ft./hr. at 330° C. is 134 cu. ft./hr. of gas. This calculation was experimentally confirmed in the three tests shown in Table III, and it will be seen that the increase in heat requirements over an unpurged furnace amounted to approximately 20%.

TABLE II.—CONDITIONS IN FURNACE BEING BROUGHT TO ENAMELLING TEMPERATURE

Gas rate, (cu. ft./hr.)	Forced Air		Furnace Pressure, (in. w.g.)	CO_2 in Furnace		
	Volume, (cu. ft./hr.)	Temp. (°C.)		Top	Centre	Bottom
144	0	0	0·01	12·7	12·6	12·9
144	250	270	0·02	—	—	4·3
115	450	335	0·04	1·5	1·3	0·7
115	500	340	0·04	3·0	2·0	1·3

TABLE III.—DETAILS OF THREE TEST RUNS

	Test A	Test B	Test C
Air Blown In (cu. ft./hr.)	350	400	450
Temperature (° C.)	380	400	360
CO_2 (without blown air) (%)	11·3	11·3	11·3
Furnace Temperature (° C.)	965	965	922
CO_2 in Furnace—Hearth Level (%) ..	1·6	1·6	0·7

Conclusions

Satisfactory enamelling of delicate colours can be continuously achieved in an open town-gas fired furnace with local dilution of products of combustion to a carbon dioxide concentration of 1% or less. This confirms the view put forward by Ryder & Culshaw in a paper to the Institute of Vitreous Enamellers in October, 1949. It is estimated that the cost of operating such a furnace in order to obtain local dilution of products in the vicinity of the work would be approximately 20% more than that for operating the standard open fired furnace.

The following conditions appear to be necessary for successful operation :

(1) The use of an underfired furnace with combustion conditions set to give maximum carbon dioxide concentration and, therefore, minimum volume of products of combustion with maximum heat transfer around the working chamber.

(2) A ventilated arch to give maximum scrubbing effect of the gases and at the same time a minimum resistance to flow and avoidance of turbulence.

(3) A suitable recuperator in the outgoing products stream to produce preheated air for purging.

(4) A perforated working hearth permitting the passage of hot air for dilution at low velocity.

Further Work

The series of tests so far reported give sufficient indication of the practicability of using this method to warrant the continuance of further tests on a larger scale. The West Midlands Gas Board propose to modify one of their own furnaces, a 6 ft. by 4 ft. underfired heat treatment furnace, to operate under the proposed conditions, and to issue a further report in due course.

Manganese Bronze Reorganisation

A REORGANISATION to integrate production facilities and co-ordinate sales of two subsidiaries has been undertaken by the £3¾-million Manganese Bronze and Brass Co., Ltd., London, whose interests range from the manufacture of ships' propellors and brass and aluminium castings to high precision machine manufacture and general engineering. As a result of the reorganisation the two subsidiaries—Dean and Son (Yorkshire), Ltd., of Beverley, and Lightalloys, Ltd., of Willesden, London—went into voluntary liquidation, and emerged as the Deans and Lightalloys Division of The Manganese Bronze and Brass Co., Ltd., with a central sales office at 10–12 Cork Street, London. At the same time, all production facilities for the new division will be housed in a large modern foundry in Beverley, Yorkshire, which will be the largest aluminium foundry in the North of England. The lightalloy factory at Willesden will be closed down.

Structural Factors Affecting the Creep Properties of Precipitation-Hardened Nickel-Chromium Alloys*

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The Mond Nickel Company, Ltd., London

The principal factors which must be taken into consideration in the development of creep-resisting nickel-chromium alloys are summarised. These include compositional effects, divided into those appertaining to the matrix, to the formation of precipitable phases and to minor constituents whose structural significance is not, in all cases, understood. The influences of processing procedure, of heat treatment and of the size of the test-bar in relation to that of the article for which the alloy is to be used, are also dealt with.

THE binary nickel-chromium alloys, usually containing about 20% of chromium, have been well known for many years for their high resistance to oxidation at elevated temperatures, and hence it was natural that, when the need for alloys with high creep-resistance at temperatures of 700° C. or higher first became apparent, this system should be investigated as a possible basis for engineering materials. The initial work in this field was carried out about twenty years ago and was aimed solely at strengthening the basic binary alloy to the extent of giving adequate creep-resistance in tests lasting for only a few hundred hours. This was considered the relevant requirement for the application of materials to the aircraft gas turbine then being developed. The required properties were achieved by the incorporation of small percentages of titanium and aluminium in the basically solid-solution alloy, these additions being sufficient to make the alloy susceptible to precipitation-hardening after suitable heat treatments. Subsequent developments of this basic alloy have been such as to satisfy a demand for similar mechanical characteristics at progressively higher temperatures, and it is interesting to note the steps in the alloys commercially available in Great Britain, in terms of the temperature at which a life-to-rupture of 100 hours is obtained under a fixed stress. This is illustrated in Fig. 1, and it is seen that over a period of fifteen years a rise in permissible operating temperature of 140° C. has been achieved. A great deal of the progress obtained in this field has followed from empirical exploration of the effects of many possible variables, but in the course of this work an appreciation of the more fundamental factors which control and contribute to high-temperature strength has been gathered, and it is proposed in this paper to review these factors.

Although the paper is concerned almost exclusively with the factors contributing to creep-resistance and to stress-rupture strength, it must be remembered that for satisfactory high-temperature service many mechanical properties other than the creep characteristics are of importance, and in many cases adequate resistance to corrosion by the surrounding medium can be the critical factor in deciding the serviceability of a given material.

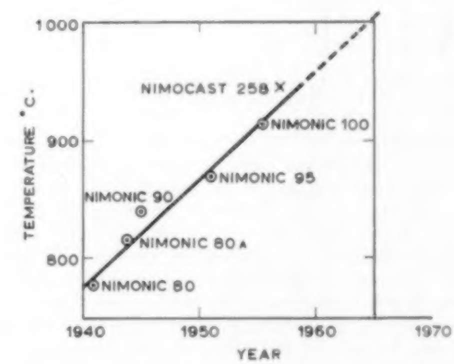


Fig. 1—Plot of progress in Nimonic alloys in terms of temperature for rupture in 100 hours at 9½ tons/sq. in.

Resistance to corrosion becomes of greater importance as the desired service temperature rises, and it is well known that molybdenum-base alloys, which have appreciably higher mechanical strength and creep-resistance than the best available nickel- or cobalt-base alloys at temperatures in the region of 1,000° C. have not found application, except in a few special cases, because of their very inadequate resistance to oxidation.

Effect of Composition

All the constituent elements in a high-temperature alloy, whether they are the constituents comprising a large proportion of the composition of the alloy, or whether they are only present in trace quantities, play a significant part in determining the potential creep characteristics of the finished alloy. In order to consider systematically the function of the different constituents it is desirable to review them in groups, according to the constitutional part that they play in the formation of the alloy. The characteristics of the elements falling into different structural groups differ quite widely, and each of these groups will be considered in turn.

Elements in Solid Solution

It is self-evident that the major constituent of an alloy to operate at high temperatures shall have as high a melting point as possible, in order to resist thermally-

* Presented at a Symposium on Problems of Development of Creep-Resisting Materials held at Marienbad, Czechoslovakia, September, 1959, and published in Czech in *Hutnické Listy*, 1959, **14** (12), 1133.

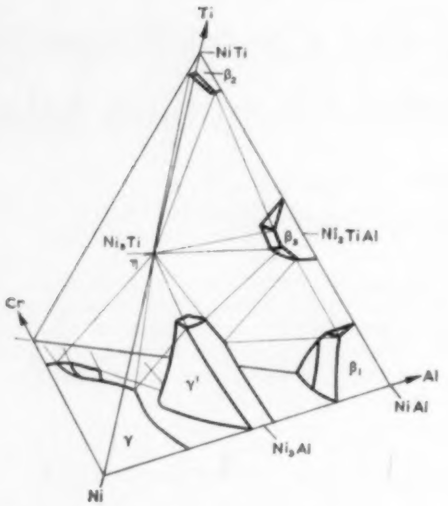


Fig. 2—The nickel-chromium-aluminium-titanium system at 750° C.

activated processes of atomic mobility. Since economic factors also play their part in alloy development it is clear that the transition elements iron, nickel, and cobalt should be considered as the most likely major constituents of such alloys. Of these three, nickel is technically the most attractive, for two or three reasons, in spite of having slightly the lowest melting point of the metals in this group. In the first place, nickel has a face-centred-cubic structure which is known to be the most satisfactory of the three common metallic structures for the development of high creep-resistance. This is probably due to the fact that, on the one hand it is a denser structure than the body-centred-cubic structure, and also that it has four possible slip planes, in comparison with the single slip plane of the close-packed-hexagonal structure. The four slip planes lead to mutual interference of slip mechanisms within a single grain, whereas in the hexagonal structure, slip within a single grain proceeds relatively unimpeded. A further advantage of nickel is that the face-centred-cubic structure remains unchanged from normal temperatures up to the melting point, whereas both iron and cobalt undergo phase changes with rising temperature. In addition to these structural factors nickel has reasonable oxidation-resistance, both at normal and elevated temperatures, superior to that of either iron or cobalt. It is understandable, therefore, that nickel has proved a very satisfactory major constituent of the basic solid solution of high-temperature alloys.

Other elements entering into solid solution in the matrix of the alloy may exert a favourable influence with regard to creep-resistance, acting by one, or both, of two mechanisms. If the melting point of the solute element is higher than that of nickel it will increase to some extent the thermal stability of the solid solution, which is evidenced by the higher annealing temperature required and the higher temperature of recrystallisation. A further factor is that the different atomic size of a solute element produces, in the crystal lattice, disturbances which interfere with the easy movement of dislocations along the slip planes. Thus, the wider the disparity between the atomic sizes of the solute and of the solvent the greater should be the effect of specific atomic proportions of solute elements. It is well known, however, from the work of Hume-Rothery[1] that only in the case of elements not differing by more than 15% in atomic size from that of the solvent, will wide ranges of solubility be obtained. The desirable aims of high solubility and large difference in atomic size are therefore to some extent incompatible. Harris and Child[2] have indicated the importance of a complexity factor significant in relation to the strengthening effect of carbides in a cobalt-base high-temperature alloy: the presence of three carbide-forming elements was found to produce a more stable material than was obtained by an equivalent proportion of a single carbide-forming element. It appears probable that a similar complexity effect applies with regard to the elements in solid solution in the matrix, smaller proportions of a number of solute elements being more effective in stabilising the lattice than an equivalent quantity of a single solute element. Again, it can readily be appreciated that a number of differing atoms of varying sizes distributed throughout the crystal lattice would introduce more serious obstacles to the movement of dislocations than would a mixture of only two different atom types. It is interesting to note, therefore, that in the commercial alloys of the Nimonic* series and the corresponding casting alloys, the number of constituents in the solid solution increases with increasing high-temperature strength of the alloy. This is illustrated in Table I.

TABLE I.—ELEMENTS IN SOLID-SOLUTION MATRIX OF NIMONIC ALLOYS.

Alloy	Elements
Nimonic 80	Ni–Cr
Nimonic 90	Ni–Cr–Co
Nimonic 100	Ni–Cr–Co–Mo
High-Strength Casting Alloys ..	Ni–Cr–Co–Mo–W

Following this line of thought, it is interesting to review all the elements of the periodic system and to consider which of those not yet used holds promise for addition to the solid solution of high-temperature alloys. It will be found that the following elements attract interest in this respect because their melting points are higher than that of nickel: niobium, tantalum, vanadium, rhenium, the platinum metals, boron and zirconium. Vanadium can be excluded on account of its known unfavourable effect on oxidation-resistance, while boron and zirconium can also be excluded because of the very limited solid solubility of these elements. Niobium and tantalum are known to act in a similar manner to titanium, in forming the type of intermetallic precipitable phases discussed in the next section. The remaining elements, rhenium and the platinum-metal group, are all economically unsuitable except for inclusion in trace quantities, so that it is unlikely that further progress can be made in increasing the complexity of the basic solid solution of high-temperature alloys, except by variation of the proportions of the elements already in use. One exception is to be noted: that is the general avoidance of iron in this group of alloys. Fundamentally there seems very little reason for this, and it may well be that omission of iron stems from the fact that early exploration of the effect of this element was made with relatively

* Registered Trade Mark.

impure material, so that the iron addition carried with it deleterious elements. It is possible that further investigation, using the purest possible iron as the addition material, would give more favourable results.

Elements Producing Precipitated Phases

The observation that additions of a few per cent. of either titanium or aluminium would confer precipitation-hardening characteristics on nickel-chromium alloys was first reported by Chevenard[3] but the importance of this precipitation-hardening in connection with creep-resistance was not then appreciated. When, however, attempts were being made to increase the creep-resistance of nickel-chromium alloys it was natural to turn to the constitutional systems in which it was known that age-hardening could be produced. The initial work leading to the introduction of precipitation-hardened nickel-chromium alloys as creep-resisting materials has been described by Pfeil, Allen and Conway.[4] This report reveals a full appreciation of the importance of precipitation-hardening for development of high creep-resistance, but although the presence of aluminium in the alloys examined is noted, the major hardening effect is ascribed to the titanium content. It was only in work published later that the structural importance of the relatively small aluminium content was clearly described. In order to appreciate this point it is necessary to consider the constitutional diagram of the quaternary nickel-chromium-titanium-aluminium system. A perspective drawing indicating the equilibrium conditions at 750° C. is illustrated in Fig. 2. This shows that, dependent on the composition of the alloy, two different phases can be precipitated from the nickel-rich solid solution γ : these are the intermetallic compound of stoichiometric composition Ni_3Ti, termed η, and the phase of wide compositional extent based on Ni_3Al, and termed γ'. This latter phase is isomorphous with the solid solution γ, and, indeed, over an appreciable range of compositions, has a lattice parameter very similar to that of the solid solution with which it is in equilibrium. For the alloys of practical importance, containing about 20% of chromium and with additions of 2–3% of titanium and 1–2% of aluminium, the structural characteristics are more clearly indicated in Fig. 3. This shows a plane section across the model of Fig. 2 between the three points representing the compositions Ni_3Cr, Ni_3Ti and Ni_3Al. Ni_3Cr is an alloy containing 22·8 wt. % of chromium, and the additions of titanium and aluminium referred to above bring the composition to the vicinity of the black spot marked on the diagram. It will be seen that in an alloy of this composition, in spite of the titanium content being higher than the aluminium content, the precipitated phase is γ', isomorphous with the solid solution. The lattice parameters of the precipitated phase and of the solid solution are very similar, and for the alloy marked by the spot in Fig. 3 the approximate parameters for equilibrium at 750° C. are 3·550 Å for the solid solution, and 3·578 Å for the precipitated phase. It is probably the close similarity of structure of these two phases which is responsible for the stability of the duplex structure, and the considerable resistance to over-ageing on long-time heating, although if exact equality of parameters were obtained, the precipitate, epitaxially oriented with respect to the matrix, would be unlikely to offer appreciable resistance to the movement of dislocations, and would therefore not help in the development of creep-resistance. Hagel

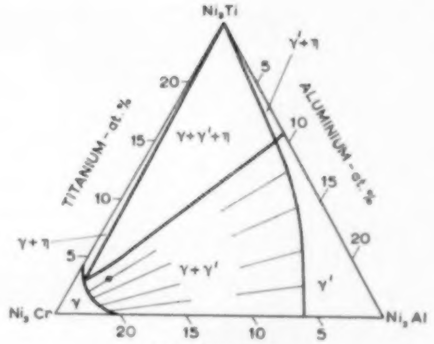


Fig. 3—The Ni_3Cr-Ni_3Ti-Ni_3Al pseudo-ternary phase diagram at 750° C.

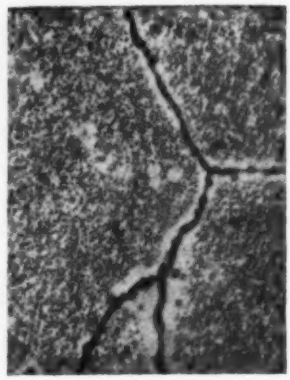
and Beattie[5] have compared the parameter misfit of the γ' precipitate and the matrix for a number of alloys and concluded that the morphology of the precipitate is related to the misfit, less than 0·4% discrepancy yielding a spherical form, 0·4 to about 1% giving a cubic form, and over 1% a cellular form which appeared relatively unstable. No indication was given, however, of any relationship between morphology and high-temperature properties. It is particularly convenient that the wide extent to which aluminium in the Ni_3Al structure can be replaced by titanium permits the favourable γ' precipitate to be formed with a relatively small addition of aluminium, and a correspondingly larger addition of titanium. Because of its low melting point aluminium must be regarded as an unfavourable material to be present in solid solution in the matrix of the alloy, whereas titanium, with its high melting point and its wide disparity in atomic size compared with nickel, must generally be regarded as advantageous. There is indeed evidence (see Betteridge and Smith[6]) that a large part of the effect of titanium in improving the creep-resistance of nickel-chromium alloys is to be ascribed to its effect in solid solution, rather than to its influence in the form of a precipitated second phase.

In spite of extensive searches to find other addition elements, to produce alternative and superior precipitation-hardening mechanisms in alloys of this type, this one method has been adopted for almost all commercial nickel-base creep-resisting alloys. While appreciable variations have been adopted, both in the total content of titanium and aluminium, and in the relative proportions of the two metals, the basic precipitation mechanism remains constant. For the reasons mentioned earlier, it is to be expected that the titanium content would be kept as high as possible and the aluminium content as low as possible, consistent with retaining γ' as the precipitating phase, and this presumption is supported by the fact that titanium-free alloys containing sufficient aluminium to produce precipitation of the γ' phase have relatively poor creep-resistance at elevated temperatures compared with that of structurally similar alloys in which a proportion of the aluminium is replaced by titanium.

In addition to the major precipitation-hardening phases introduced by additions of titanium and aluminium, smaller quantities of other phases occur in the alloys : these have been identified as carbides or nitrides.

Fig. 4 (left)—Chromium carbide at grain boundaries of Nimonic 80A. × 500.

Fig. 5 (right)—Impoverished zones near the grain boundaries of Nimonic 90 due to precipitated carbides. × 1,000.



Rectangular particles of primary titanium carbide or nitride are readily-recognisable constituents of all titanium-containing alloys. These particles, particularly the nitride, are little affected by heat treatment, and appear to play no part in the generation of good high-temperature properties other than acting to some extent as restrictors of grain-growth when they are uniformly dispersed throughout the alloy. There is a danger, however, of their joining up to form unwelcome stringers, and on this account it is desirable to keep their content to a minimum. Although the content of nitrogen can be controlled, and kept low by the adoption of suitable melting conditions, the carbon content of the alloys needs, for other reasons, to be maintained at an optimum level. It is found that, in spite of the high affinity of titanium for carbon, some carbon remains dissociated from the titanium, and at temperatures above about 1,150° C. is dispersed in solid solution in the matrix, but that at lower temperatures it precipitates in the form of a chromium carbide or of a complex carbide of other constituents of the alloy. Chromium carbides are particularly noticeable in the alloys based on the binary nickel-chromium solid solution, and in such alloys have been identified, by Betteridge and Franklin,[7] as either Cr_7C_3 or $Cr_{23}C_6$, depending on the temperature at which the alloy had been heated. The occurrence and structure of these carbides has been studied at some length by Beattie and VerSnyder,[8] and it is clear that the higher carbide is formed by the normal heat treatment of the alloy, but that during service at temperatures in the region of 700°–900° C. this compound transforms gradually to the lower carbide. The influence of chromium carbides on the creep characteristics of the alloy is closely tied with the effects of heat treatment, which will be discussed later, but it is clear that some carbon content is essential to the good characteristics of the alloys ; alloys of very low carbon content have poor properties, and creep-rupture failures occur in short times, at very low values of creep extension. Betteridge and Franklin[7] have proposed that some grain-boundary precipitation of chromium carbide is essential in order to produce chromium impoverishment in the vicinity of the grain boundaries and thereby give ductile zones which allow the accommodation of grain-boundary distortions without propagation of intergranular stress-rupture cracks. Photomicrographs showing grain-boundary precipitation of chromium carbide and impoverished zones in which no γ' precipitation occurs adjacent to the grain boundaries are illustrated in Figs. 4 and 5, respectively.

Minor Constituents

The third group of elements entering into the composition of these alloys consists of those which are present in such small proportions that generally it is not possible to detect their presence by microscopic observation of the resultant phases, and hence their constitutional significance can be deduced only by inference. Some of these elements have a favourable influence on the high-temperature strength characteristics ; others are detrimental. The detrimental ones are generally those which have relatively low melting points, and do not enter into solid solution in the matrix nor form stable intermetallic compounds, so that they remain at the grain boundaries of the matrix as traces which become molten at sufficiently elevated temperatures. If the service temperature of the alloys is above the melting point of such trace elements the resultant effect is that the alloy suffers relatively rapid intergranular disintegration due to penetration by the molten phase under the influence of the applied stress. The effect is the same as the well-known phenomenon of stress-corrosion by molten metals and can be exemplified by the results of Kishkin and Nikolenko[9] relating to the influence of surface contamination by bismuth and lead on the rupture strength, at 700° C., of the nickel-chromium alloy EI 437 ; they reported reduction in the 100-hour rupture strength from 40 kg./sq. mm. to 7 kg./sq. mm. It can therefore readily be understood that quite small contents of lead or bismuth in the alloys themselves seriously reduce the high-temperature strength.

On the other hand, some other elements present in small traces are beneficial to high-temperature strength ; perhaps the best known of these are boron and zirconium.[10] Systematic studies of the influence of these elements on creep properties have been reported by Decker and Freeman,[11] whose attention was drawn to the effect by fortuitous reactions occurring between the molten alloys and the refractory materials in which they were being melted. They concluded that the favourable influence on the stress-rupture properties followed from preferential segregation of the elements to the grain boundaries, where they retarded agglomeration of the precipitated carbide and γ' phases. In the absence of these elements agglomeration proceeded rapidly and led to increasing impoverishment of the adjacent matrix and the eventual development of micro-cracks.

which grew and initiated brittle, premature fracture. Boron and zirconium were considered to segregate preferentially to the grain boundaries because of their wide disparity in atomic size from either the interstitial spaces or the matrix atoms, so that they are not readily taken into either interstitial or substitutional solid solution. This proposal, taken with the earlier suggestion that some matrix impoverishment adjacent to grain boundaries improves the local ductility and delays intergranular fracture, leads to the conclusion that an optimum degree of such impoverishment might be necessary to ensure the maximum stress-rupture life.

Since the mechanism by which these trace elements affect the creep characteristics of the alloys is very imperfectly understood, the desirable levels for any particular alloy have to be determined by purely empirical means. Indeed if their influence is indirect, such as by combination with otherwise detrimental impurities, the optimum levels of the favourable trace elements will vary with the impurity content of the alloy and perhaps with the technique of melting adopted.

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Processing Effects

Most of the applications of high-temperature alloys to stressed components have involved the use of wrought material, because this has generally been found to be more reliable and consistent in characteristics than cast material. More recently, however, improvements in foundry techniques are giving greater confidence in castings, and since by the use of castings it is possible to employ alloys having compositions beyond the range at which hot-working is a feasible proposition, castings may in the future find increasing use in the higher-temperature applications. For the present, however, we are mainly concerned with wrought alloys, and it is necessary to consider the way in which the hot- and cold-working procedures affect the ultimate high-temperature properties of the materials. To a large extent the influence of the working operations is removed by the subsequent heat treatment (this will be dealt with later), but even after normal heat treatment some residual effect of working remains. The operations of hot- or cold-working affect the alloy in two ways which can influence the mechanical properties. First, they severely distort the crystal lattice of the alloy, introducing a high density of lattice defects such as dislocations, vacant sites, and interstitial atoms, all of which can contribute to creep distortion under the influence of stress and temperature.

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This effect is exactly parallel to the well-known practical observation that a cast ingot is difficult to deform under hammer or press in the initial stages of forging, but once some deformation has been effected, subsequent operations are much easier. The degree of residual lattice distortion is a function of the working temperature, of the magnitude of the reduction applied, and probably also of the rate of deformation. Most practical hot-working operations are controlled in an empirical manner within limits which, by trial and error, are known to yield satisfactorily uniform properties in the product. The effect of working operations on creep properties can, however, clearly be illustrated by comparison of the characteristics of hot-rolled bar with those of cold-rolled sheet, the latter being subjected to the highest level of lattice distortion. Comparative properties of the two forms, for two alloys of the Nimonic series which have undergone appropriate heat treatment, are as given in Table II. The sheet material is consistently lower in stress-rupture strength than the hot-worked bar, and although some of the difference may be due to the form of test-bar (see section on " Specimen-Size Effect"), there is little doubt that the deleterious influence of cold-working is incompletely removed by the subsequent heat treatment.

The second way in which processing can affect the properties of a high-temperature alloy is by the production of preferred orientations of the crystal lattice. The effect is, of course, very familiar with severely-worked materials tested at normal temperatures, but no evidence has been published of a similar effect on high-temperature properties. Although it has been shown[12] that in some extruded products the longitudinal and transverse creep properties are equivalent, this cannot be taken as sufficient evidence of non-directionality in more severely deformed material, and this aspect requires more thorough study.

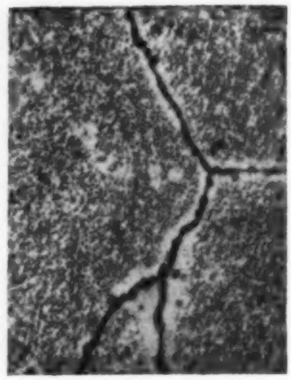
Heat Treatment Effects

Heat treatments are applied to these alloys in order to develop the full mechanical properties of which the alloys are capable, and at the same time they serve to remove, to a very large extent, the effects of prior working operations. For precipitation-hardenable materials the heat treatment procedures consist of the usual two stages, the first being the solution stage, and the second the precipitation stage. In some cases the latter stage consists of two, or even more, operations, at different temperatures. The influence of the different stages of this heat treatment on the creep properties of the material will now be considered.

A systematic study of these effects in the case of the alloy Nimonic 80A, which is based on the binary nickel-chromium matrix, has been reported by Betteridge and Franklin.[7] It was suggested from this work that the solution-treatment has two principal functions: first, to dissolve the phases which are subsequently to be precipitated to produce hardening; second, to anneal

Fig. 4 (left)—Chromium carbide at grain boundaries of Nimonic 80A. × 500.

Fig. 5 (right)—Impoverished zones near the grain boundaries of Nimonic 90 due to precipitated carbides. × 1,000.



Rectangular particles of primary titanium carbide or nitride are readily-recognisable constituents of all titanium-containing alloys. These particles, particularly the nitride, are little affected by heat treatment, and appear to play no part in the generation of good high-temperature properties other than acting to some extent as restrictors of grain-growth when they are uniformly dispersed throughout the alloy. There is a danger, however, of their joining up to form unwelcome stringers, and on this account it is desirable to keep their content to a minimum. Although the content of nitrogen can be controlled, and kept low by the adoption of suitable melting conditions, the carbon content of the alloys needs, for other reasons, to be maintained at an optimum level. It is found that, in spite of the high affinity of titanium for carbon, some carbon remains dissociated from the titanium, and at temperatures above about 1,150° C. is dispersed in solid solution in the matrix, but that at lower temperatures it precipitates in the form of a chromium carbide or of a complex carbide of other constituents of the alloy. Chromium carbides are particularly noticeable in the alloys based on the binary nickel-chromium solid solution, and in such alloys have been identified, by Betteridge and Franklin,[7] as either Cr_7C_3 or $Cr_{23}C_6$, depending on the temperature at which the alloy had been heated. The occurrence and structure of these carbides has been studied at some length by Beattie and VerSnyder,[8] and it is clear that the higher carbide is formed by the normal heat treatment of the alloy, but that during service at temperatures in the region of 700°–900° C. this compound transforms gradually to the lower carbide. The influence of chromium carbides on the creep characteristics of the alloy is closely tied with the effects of heat treatment, which will be discussed later, but it is clear that some carbon content is essential to the good characteristics of the alloys ; alloys of very low carbon content have poor properties, and creep-rupture failures occur in short times, at very low values of creep extension. Betteridge and Franklin[7] have proposed that some grain-boundary precipitation of chromium carbide is essential in order to produce chromium impoverishment in the vicinity of the grain boundaries and thereby give ductile zones which allow the accommodation of grain-boundary distortions without propagation of intergranular stress-rupture cracks. Photomicrographs showing grain-boundary precipitation of chromium carbide and impoverished zones in which no γ' precipitation occurs adjacent to the grain boundaries are illustrated in Figs. 4 and 5, respectively.

Minor Constituents

The third group of elements entering into the composition of these alloys consists of those which are present in such small proportions that generally it is not possible to detect their presence by microscopic observation of the resultant phases, and hence their constitutional significance can be deduced only by inference. Some of these elements have a favourable influence on the high-temperature strength characteristics ; others are detrimental. The detrimental ones are generally those which have relatively low melting points, and do not enter into solid solution in the matrix nor form stable intermetallic compounds, so that they remain at the grain boundaries of the matrix as traces which become molten at sufficiently elevated temperatures. If the service temperature of the alloys is above the melting point of such trace elements the resultant effect is that the alloy suffers relatively rapid intergranular disintegration due to penetration by the molten phase under the influence of the applied stress. The effect is the same as the well-known phenomenon of stress-corrosion by molten metals and can be exemplified by the results of Kishkin and Nikolenko[9] relating to the influence of surface contamination by bismuth and lead on the rupture strength, at 700° C., of the nickel-chromium alloy EI 437 ; they reported reduction in the 100-hour rupture strength from 40 kg./sq. mm. to 7 kg./sq. mm. It can therefore readily be understood that quite small contents of lead or bismuth in the alloys themselves seriously reduce the high-temperature strength.

On the other hand, some other elements present in small traces are beneficial to high-temperature strength ; perhaps the best known of these are boron and zirconium.[10] Systematic studies of the influence of these elements on creep properties have been reported by Decker and Freeman,[11] whose attention was drawn to the effect by fortuitous reactions occurring between the molten alloys and the refractory materials in which they were being melted. They concluded that the favourable influence on the stress-rupture properties followed from preferential segregation of the elements to the grain boundaries, where they retarded agglomeration of the precipitated carbide and γ' phases. In the absence of these elements agglomeration proceeded rapidly and led to increasing impoverishment of the adjacent matrix and the eventual development of micro-cracks.

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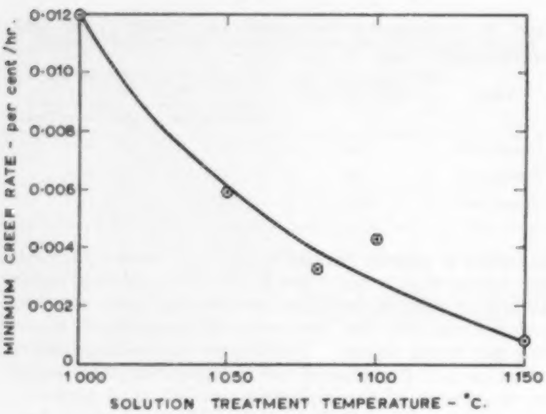

Fig. 6—Effect of solution treatment temperature on creep rate of Nimonic 80A at 17 tons/sq. in. and 750° C.

the matrix and remove the effect of prior working operations. If the effect of the treatment were solely one of taking the precipitable phases into solution no further change in creep-resistance would be expected once complete solution had been effected. The curve shown in Fig. 6 shows, however, that, even though the γ' phase is completely in solution at temperatures above about 880° C., a progressive fall in creep rate occurs as the temperature of the solution treatment increases from 1,000°–1,150° C. The explanation offered for this effect is that higher treatment temperatures give more perfect annealing of the distorted lattice of the alloy, removing, by self-annihilation and diffusion to the grain boundaries, the lattice defects which would otherwise contribute to creep deformation under the influence of an applied stress. Unfortunately, however, raising the temperature of the solution treatment inevitably leads to increasing grain-growth, and excessive grain-size is found to be undesirable for other reasons than simple resistance to creep. For these reasons a compromise is adopted, and in practice solution treatment of the alloys is normally carried out at a temperature just below that at which rapid grain-growth sets in; for Nimonic 80A this is in the range 1,050°–1,100° C. Alloys of this class which have more stable matrices, due to the presence of additional solute elements such as cobalt and molybdenum, show greater resistance to grain-growth, and it is frequently possible to use solution-treatment temperatures up to about 1,200° C.

The subsequent treatments designed to produce precipitation of the hardening γ' phase are normally carried out at temperatures close to those which the alloy is expected to reach in service. It is desirable to carry this treatment to a stage ensuring reasonable stability, in order that precipitation during actual service shall be reduced to a minimum, as it is to be expected that atomic movements arising in the course of precipitation would contribute to creep deformation. Studies of the effect of ageing temperature on the shape of the creep curves for Nimonic 80A have been reported by Betteridge and Franklin,[13] and these showed that the greatest creep-resistance is shown with ageing temperatures not seriously exceeding the subsequent temperature of creep-testing. Higher ageing temperatures, up to the temperature for complete solubility of the γ' phase, gave less creep-resistance, and shorter stress-rupture lives, but higher elongations at rupture. It is probable that these differences in creep characteristics are to be correlated with the differing size and distribution of the precipitated particles of γ', the larger and more widely separated particles of precipitate offering less resistance to creep deformation. For some special applications of these alloys in which high creep-elongation at rupture is required, it has been found convenient to use two stages of precipitation, the first being at a relatively high temperature, and producing widely dispersed coarse particles, and the second at a lower temperature, filling the interstices between the first precipitate particles with finer and more closely spaced particles. By this means a useful compromise, with good creep-resistance and adequate elongation at rupture, can be obtained.

In dealing with the effects of heat treatment it is useful once again to refer to the optimum distribution of chromium carbide at the grain boundaries. It will be remembered that these carbides are considered desirable *at the grain boundaries* in order to produce some impoverishment of the adjacent matrix, and thereby give sufficient ductility to prevent early, brittle, intergranular rupture. With levels of carbon content in the region of 0·1% these carbides are fully dissolved in the solid solution at temperatures of about 1,150° C. and higher; consequently, if solution-treatment is carried out in this range of temperatures, and is followed by relatively rapid cooling, no grain-boundary carbide-precipitation will occur. Subsequent ageing at lower temperatures usually results in general precipitation of carbide *within the grains*, which does not have the desired beneficial effect on the creep characteristics. Satisfactory intergranular carbide-precipitation can be produced either by relatively slow cooling from a high solution-treatment temperature, or by reheating to a temperature not far below that at which the carbide is dissolved. In the case of Nimonic 80A a reheating temperature of 1,050°–1,100° C. produces this effect, and it will thus be appreciated that the normal solution temperature adopted for these alloys is effective also in ensuring that satisfactory grain-boundary carbide-precipitation takes place. If, with this or other similar alloys, a high solution temperature has been used in the interest of obtaining the highest possible creep-resistance, it is therefore essential that a subsequent treatment at 1,050°–1,100° C. be applied, in order to precipitate carbide before applying the true ageing treatments which cause precipitation of the γ' phase. It can thus be seen that when it is necessary to develop special creep characteristics three- or even four-stage heat treatments may be required.

Specimen-Size Effects

A further factor which exerts some influence on the measured creep characteristics of an alloy, but which is mainly of concern to the engineer wishing to use the measured properties in design calculations, is that relating to the size of the test bar on which the properties are measured. For the metallurgist concerned with the development of new or improved alloys it is mainly of importance in comparing results obtained by different laboratories. The significance of this factor is well exemplified by results reported by Shahinian and Lane[14] relating to two alloys, one a high-temperature creep-resistant alloy, the other a nickel-copper alloy. For both alloys, for specific conditions of creep-testing, it was found that the properties remained reasonably constant if the ratio of the diameter to the length of the

test bar remained constant. Decrease of this ratio, however, increased the minimum creep rate and decreased the stress-rupture life. A change in the ratio by a factor of 32 produced a more than two-fold change in creep rate, and a change in life by a factor of 5. Differences of a similar order are observed for precipitation-hardened nickel-chromium alloys: the effect is believed to be complex, comprising the influence of stress distribution on purely geometric grounds, of surface-corrosion effects, and of grain-size in relation to specimen diameter. In design considerations, therefore, it is necessary to consider the creep properties of the material in relation to the size of the test bar on which they are determined, and the size of the component to which they are applied.

Conclusion

From the foregoing review it is clear that the development of new high-temperature creep-resisting alloys must be undertaken in the light of all the factors which might influence the properties ultimately to be obtained in service. The content of major alloying elements is, of course, of primary importance, but the testing and interpretation of the effects of variations in composition must be made with a full realisation of the influence of other important factors. Prominent amongst these are the contents of elements present in only very minor proportions, the methods of processing the cast ingot to test bar, details of heat treatment procedure in the light of the structural changes being effected, and the properties determined on test bars in relation to those called for in the finished components.

Acknowledgment

The author's thanks are due to The Mond Nickel Company, Ltd., for permission to contribute this paper.

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Non-Ferrous Metals in 1959 and Trends for 1960

A REPORT by the O.E.E.C. Non-Ferrous Metals Committee containing statistics for 1959 and trends for 1960, has now been published. The main body of the report brings up to date the statistical information on production, consumption, imports and exports and metal uses at the first processing stage, as collected by the Committee. A statistical series for aluminium end-uses is included with figures for 1958 and 1959; this means that for the first time, the flow of processed aluminium to the various consumer industries has been put on a comparable basis for European countries.

The topical interest of the publication is enhanced by the brief survey (Part 1) on market developments in 1960 made by the Committee at the end of October, which also includes short-term forecasts on the activity of European non-ferrous metals industries. 1960 was a record year for European non-ferrous metals production and consumption, as well as for imports. The upward trend of activity continued unabated for the first nine months, but the Committee felt that it might weaken somewhat towards the end of the year and early 1961, mainly due to the limited amount of capacity and manpower—particularly the latter—available, as well as credit restrictions in some countries designed to ease the pressure of demand before it leads to inflation.

Progress in processing industries, particularly for aluminium and copper, has been quite spectacular, and the production of aluminium and copper semis and castings is reported in some countries to be 25–30% up on the first half of 1959. Although some new capacity has now come into service, deliveries are still abnormally slow in some cases. In the zinc processing industry, the greatest expansion was made in die castings and brass products. According to the exports, zinc and aluminium die-castings are now meeting with more and more competition from plastics, e.g. for motor vehicle accessories. Demand for lead products remained stable, but demand for nickel steel and anodes was stimulated by the insistence on better finishing for consumer durable goods and the export market.

The second part of the report describes the expansion of the European non-ferrous metals industries in the nineteen-fifties. The progress made by producer and consumer industries and the changes that took place during this period in the pattern of European consumption and trade are set forth in this analysis, which is based on the statistics collected during the last ten years and related to the general economic background during this period. The non-ferrous metals industry in the O.E.E.C. countries has been in continual expansion since 1950, to a much more marked degree than any other areas in the Western world. Both production and consumption rose by over 50% and net imports more than doubled, thus increasing considerably the overall dependence of the area on raw materials supplied from outside. Whereas the O.E.E.C. area has maintained its proportion of output in the Western World at slightly more than one-quarter, its relative importance as consumer increased and is now approaching that of the United States.

Castrol Engineering Division

MR. R. ADAMS has been appointed general manager of a newly created engineering division of Castrol, Ltd., which has been formed to bring together and intensify the expanding engineering operations of the group. These consist of the design, manufacture, installation and servicing of a very wide range of lubricating plant and equipment for both automotive and industrial applications. The new division includes the following four departments: lubrequipment (automotive lubricating equipment); mechanical appliances (industrial lubricating equipment); service; and drawing office.

New and Revised Standards

Steel Sheets for Magnetic Circuits of Power Electrical Apparatus: Part 2: Oriented Steel (B.S.601: Part 2: 1961). Price 5s.

Unlike the earlier edition of B.S.601, published in 1935, the new edition is in two parts. Part 1, covering non-oriented steel, was published in 1959: Part 2 has now been published. It covers oriented magnetic steel strip and sheets intended primarily for machines and transformers operating at power frequencies, and applies to material which will be supplied in one nominal thickness only and in four grades. The specification deals with material coated on both sides with a suitable insulation capable of withstanding stress-relief annealing under conditions approved by the manufacturer. Tests are laid down for total losses and A.C. excitation, effect of ageing, stacking factor and insulation values. Test procedure and formulae and typical values are included in the five appendices.

Analysis and Testing of Coal and Coke: Part 10: Arsenic in Coal and Coke (B.S.1016: Part 10: 1960), Price 6s.

The revised edition of B.S.1016, "Methods for the Analysis and Testing of Coal and Coke" is now nearly complete, Parts 1–9, 11, 12 and 15 having already been issued. Part 10, dealing with the determination of arsenic in coal and coke, has just been published and is of particular importance to those industries, such as food processing and steel manufacturing, where traces of this element can have serious effects.

Two methods are described, a colorimetric method and a modified Gutzeit method using a paper stain finish. For the colorimetric method, two alternative procedures are specified to oxidise the sample. The paper stain method has been modified from that given in B.S.1016: 1942, in that improvements in apparatus and technique have been made and the procedure has been more closely defined. Both these methods have been found to give more reliable results than the original Gutzeit method and the electrolytic method described in B.S.1016: 1942, which they replace, although the paper stain method has somewhat wider tolerances.

Analysis of Iron and Steel: Part 42: Cobalt in Iron and Steel (B.S.1121: Part 42: 1961), Price 3s.

The British Standards Institution has just published the 42nd in the series of methods for the determination of elements in iron and steel and related products. This method is for the photometric determination of trace amounts (between 0·002 and 0·04%) of cobalt. A method (Part 30) has already been issued for determining larger quantities of cobalt up to 12%.

Glossary of Coal Terms (B.S.3323: 1960), Price 5s.

This much-needed British Standard defines terms used in the petrography, classification, analysis, marketing and utilisation of coal in the United Kingdom. These terms are in many instances related to the National Coal Board's classification system for coal, which is set out in an appendix. Another appendix lists the sizes of commercial grades of coal. Coal sampling terms are not given, as these are covered by B.S.1017, "The Sampling of Coal and Coke," Part 1. Terms used mainly in coal preparations are also omitted, because a comprehensive British Standard glossary on this subject will shortly be published separately. Various terms have been excluded from the glossary because they are purely local descriptions, because their meaning is self-evident, or because they merely indicate the geographical origin or method of extraction of a coal. Represented on the committee which prepared the standard were: the Chamber of Coal Traders, the Electricity Council, the Generating Board and Area Boards in England and Wales, the Gas Council, the Institute of Fuel, the Ministry of Power and the National Coal Board.

Copies of these standards may be obtained from the British Standards Institution, Sales Branch, 2 Park Street, London, W.1. (Postage will be charged extra to non-subscribers.)

Oxygen-Lime Powder Blowing

A 30 ton converter is working on three shifts at Dillingen in the Saar for the conversion of high phosphorus hot metal to steel. Lining lives of 200 heats are being obtained utilising a combination of metallurgical and technological features detailed from the start by IRSID, the French iron and steel research institute, which has been a pioneer in this type of lime blowing. It is important to avoid foaming of a siliceous slag at the beginning of the blow, and incorrect lime consumption may give this. Of primary importance, the complete lime blowing installation devised by IRSID after several years of systematical research gives the necessary reliability and flexibility. Dephosphorisation is well under control and there is no difficulty in making regularly low-carbon steels with low phosphorus. Moreover, from recent developments it appears that carbon steels up to at least 0·5% C can be made from 1·8% P hot metal.

At Usinor, Denain, a 60 ton converter blowing high phosphorus hot metal has just started. Lime powder rates of half a ton a minute are reached. In the new plant under construction at Dunkirk, hematite hot metal will be refined in 140 ton converters by the O.L.P. process.

Unusual Coil Annealing Furnaces

A battery of four unusual coil annealing furnaces which use an oil-fired radiant tube heating system, has been ordered by James Booth Aluminium, Ltd., from AEI-Birlec, Ltd. The equipment, costing well over £100,000 incorporates a number of features which are expected to have a significant influence on European aluminium mill practice. It will be installed in their Kitts Green Works, Birmingham, as part of James Booth's £5 million re-equipment and expansion programme which is scheduled for completion next year.

Each of the four furnaces has a usable chamber 6 ft. high, and measuring 20 ft. by 14 ft., which will take a 32-ton charge of coiled aluminium strip. Heating is by batteries of temperature-controlled, oil-fired, radiant heating tubes, over which the furnace atmosphere is circulated at exceptionally high speeds by eight powerful motor-driven fans. The charge is also cooled in the furnace, at a controlled rate, before being discharged.

Heat treatment
Tomatoes grow fat and ripe in the controlled heat of the greenhouse—and metal parts receive the best heat treatment in 'Cassel' salt baths.
With salt baths as with greenhouses, what counts is experience. The 'Cassel' Heat Treatment Service has long experience in carburising, heat treatment, tempering, martempering and austempering.
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NEWS AND ANNOUNCEMENTS

The Institute of Metals

ELECTION OF HONORARY MEMBER AND FELLOWS

THE council of The Institute of Metals has elected PROFESSOR W. HUME-ROTHERY, O.B.E., F.R.S., Isaac Wolfson Professor of Metallurgy in the University of Oxford, as an Honorary Member of the Institute.

The council has also elected MAJOR C. J. P. BALL, D.S.O., M.C.; DR. MAURICE COOK, C.B.E., and LIEUT.-COLONEL S. C. GUILLAN, T.D., as Fellows, in recognition of the services that they have rendered to the Institute.

ELECTION OF OFFICERS

The following members have been declared elected to fill vacancies that will occur on the council of The Institute of Metals at the forthcoming annual general meeting:

President: PROFESSOR H. O'NEILL.

Vice-Presidents: MR. W. F. RANDALL and THE RIGHT HON. THE EARL OF VERULAM.

Ordinary Members of Council: MR. N. I. BOND-WILLIAMS, PROFESSOR A. H. COTTRELL, F.R.S., and MR. G. A. RIDER.

The council has elected THE EARL OF VERULAM to serve as senior vice-president for the year 1961–62.

Corrosion Essay Competition

THE Education Panel of the Corrosion Group, with the approval of the council of the Society of Chemical Industry, established in 1955 a competition designed to encourage those who are still in the early stages of their career to take an interest in corrosion science and to express their ideas in writing. With the support of industrialists interested in the application of corrosion science in industry, a prize of the value of 25 guineas will again be awarded this year for an essay or paper on any aspect of corrosion of metals and its prevention.

Essays are invited from persons aged not more than 30 years on the closing date (31st March, 1961). A length of about 4,000 words is suggested, but reasonable latitude is allowable. Judgment of the entries will be based on the evidence shown of the candidate's critical faculty and originality of thought, and on technical and literary excellence generally. Results of original research may be incorporated, but this is not essential; entries may consist, for example, of surveys of knowledge in a particular field, discussion of practical problems, and suggestions for future developments in research, in application of knowledge, or in organisation of corrosion-preventive measures. Where the work or ideas of others are referred to, clear acknowledgment must be made. A successful candidate may subsequently be invited to deliver his or her contribution as a lecture.

Further particulars may be obtained from the Society of Chemical Industry, 14 Belgrave Square, London, S.W.1.

Metal Fracture Course

A VACATION course on "The Fracture of Metals," organised by the Metallurgy Department, will be held at Battersea College of Technology from April 11th to 14th, 1961. The course, of three and-a-half days' duration, is intended to give an overall picture of recent work in this field. All lecturers have been selected for their first-hand knowledge of the subject, and the topics to be covered will include: the practical problems of fracture in service; mechanical testing methods for the assessment of fracture behaviour; theoretical aspects of fracture; the ductile-to-brittle transition in ferrous and non-ferrous metals; the effect of irradiation on fracture behaviour; temper brittleness in steels; hydrogen embrittlement of metals; fracture under creep conditions; and fracture under fatigue conditions. There will be ample opportunity for questions and discussion. The fee for the course is ten guineas (inclusive of luncheon, and morning and afternoon refreshment). Enrolment forms may be obtained from the Secretary (Metallurgy Courses), Battersea College of Technology, London, S.W.11.

B.I.S.R.A. Open Days at Sheffield

THE British Iron and Steel Research Association will hold two Open Days at its Sheffield Laboratories on Thursday and Friday, June 15th and 16th, 1961. The last occasion when the Hoyle Street group of laboratories held "open house" for representatives of member firms was in 1956. This year's function will therefore give visitors the opportunity of examining the many developments which have taken place since then.

The Hoyle Street premises house three of B.I.S.R.A.'s five main divisions—steelmaking, metallurgy (general) and mechanical working. In addition, the steel user section, which operates an important advisory service to industry generally, is also housed there. Among the many displays and demonstrations planned by the steelmaking division will be the latest developments in continuous casting, and work on spray refining and rapid de-sulphurisation. One of the mechanical working division's projects on show will be a recently-developed rapid annealing system. Prominent among the metallurgy division's projects will be aspects of its general pre-occupation with the purification of steel (jet degassing, vacuum casting, etc.), work on improved speed and accuracy in analysis, and the production of high-temperature steels. All these examples are arbitrarily selected, and represent only a few of the many projects which will be on show.

Engineers to Discuss Rolling Mills

THE engineering aspects of rolling mills will be the subject of the 42nd meeting of The Iron and Steel Institute's Engineers Group on Wednesday and Thursday, March 1st and 2nd, 1961. Mr. F. B. George (Consett Iron Co., Ltd.) will be in the chair at the meeting, which will be held at 4 Grosvenor Gardens, London, S.W.1.

The meeting starts on the afternoon of March 1st with the presentation of a paper by A. P. Clark and R. Kenderdine (Dorman Long (Steel), Ltd.) devoted to mechanical and electrical features of the Lackenby beam mill. After the presentation of the paper, there will be a discussion on the mechanical aspects of this

modern mill, which incorporates in its design many interesting engineering developments. The discussion on this paper will continue on the following morning, when attention will be given to the electrical features of the mill. The emphasis on electrical engineering will be continued at the afternoon session, at which a paper by H. D. Morgan (The Steel Company of Wales, Ltd.) and W. Spence (A.E.I., Ltd.) on the development of electric drives and control for high-speed cold-reduction mills is to be presented and discussed.

Advance copies of the two papers will be circulated to those registering for the meeting; they will subsequently be published, together with the discussion, in the Institute's *Journal*.

European Convention of Chemical Engineering

THE programme of the European Convention of Chemical Engineering which will take place from the 9th to the 17th June, 1961, in Frankfurt am Main is now available as a 32-page brochure. It indicates the scope and importance of this world famous congress for which applications have been received from fifteen countries to read 150 papers. In addition, about 1,300 exhibiting members of the Achema Congress from fifteen countries will present the latest results of their development work in the fields of chemical technology, chemical engineering and process engineering for discussion at the actual exhibits.

The brochure contains the programmes of the following meetings: Achema 1961, 13th Chemical Engineering Exhibition-Congress; Special Meeting and Lectures 1961 of the Gesellschaft Deutscher Chemiker; Annual Meeting 1961 of the Dechema Deutsche Gesellschaft für chemisches Apparatewesen; Annual Meeting 1961 of the Isotopen-Studiengesellschaft; and Symposium on "The Physical and Chemical Durability of Structural Materials in Chemical Engineering," representing the 15th Meeting of the European Federation of Corrosion. It is issued in the English, French and German languages and may be obtained on request free of charge from the Dechema Deutsche Gesellschaft für chemisches Apparatewesen, Frankfurt (Main) 7, Rheingau-Allee 25, (Postfach No. 7746).

Z.D.A.—L.D.A. Joint Director

MR. R. LEWIS STUBBS, director of the Zinc Development Association, has been appointed director-general of the Lead Development Association and the Zinc Development Association. Mr. Stubbs will be responsible for the overall direction and expansion of the work of both organisations, and will represent them at international meetings. Each association will continue to function separately under its own general manager.

Electron Diffraction Course

A VACATION course on "Applications of Electron Diffraction," organised by the Crystallography Section, will be held at Battersea College of Technology on April 13th and 14th, 1961. The course has been arranged for users and potential users of electron diffraction techniques in science and industry. The emphasis will be on practical applications rather than theoretical aspects of the subject. In view of this, the first day of the course will be devoted to lectures and discussion, while on the second day, visits will be arranged to establishments where electron diffraction apparatus is in use. The fee for the course is five guineas (inclusive of luncheon, morning and afternoon refreshment and transport for visits). Enrolment forms may be obtained from the Secretary (Crystallography Courses), Battersea College of Technology, London, S.W.11.

Computers and Creep at A.G.M.

THE Iron and Steel Institute's annual general meeting is to be held in London on May 3rd and 4th, 1961. There will be technical sessions devoted to the use of computers in the iron and steel industry and to the Brymbo oxygen steelmaking process. At the same time, a joint symposium with The Institute of Metals on structural processes in creep will be held.

Sir Charles Goodeve, O.B.E., F.R.S. (director, British Iron and Steel Research Association) will take office as president of the institute at the meeting. He will deliver his presidential address on the morning of Wednesday, May 3rd, and will take the chair at the annual dinner for members, to be held at Grosvenor House, Park Lane, that evening.

The formal business and the sessions on computers (which will be under the aegis of the British Conference on Automation and Computation) and oxygen steelmaking will take place at the Institution of Mechanical Engineers, Birdcage Walk, London, S.W.1. The joint symposium on creep will be held at the Hoare Memorial Hall, Church House, London, S.W.1.

Symposia at Borough Polytechnic

THE Division of Metal Science at the Borough Polytechnic has arranged two one-day symposia to be held in the summer term of the 1960/61 session. The first, entitled "Welding of Rarer Metals" will be held on Thursday, 20th April, 1961 and will cover electron beam welding and the welding of beryllium, uranium, titanium, Zircaloy 2, tantalum, niobium, molybdenum and tungsten.

The second symposium, on "Internal Stresses in Electrically Produced Coatings and their Effects on the Properties of the Basis Metals," will be held on Thursday, 6th April, 1961, the aspects to be treated including the measurement of internal stresses and the stresses found in electro-forming and electro-typing and in the following deposits: hard chromium and heavy nickel; bright nickel; and rhodium and platinum.

Further particulars may be obtained from the Borough Polytechnic, Borough Road, London, S.E.1.

Powder Metallurgy Meetings

THE Powder Metallurgy Joint Group of The Iron and Steel Institute and The Institute of Metals announces that a discussion on "The Appraisal of Powders for Pressing and Sintering: I.—Techniques for the Evaluation of Powders: II.—The Relationship Between Powders and their Pressing and Sintering Behaviour," will be held on Monday and Tuesday, April 17th and 18th, at The Royal Commonwealth Society, Craven Street (near Northumberland Avenue), London, W.1.

A symposium on "Sintered High-Temperature Oxidation-Resistant Materials," has been planned for Thursday and Friday, December 7th and 8th, to be held at Church House, Great Smith Street, London, S.W.1. Offers of original papers for this symposium should be sent to The Secretary, Powder Metallurgy Joint Group, 17 Belgrave Square, London, S.W.1, from whom particulars may be obtained of the contents of the Group's half-yearly periodical *Powder Metallurgy*.

An Institute of Corrosion ?

FORMATION of an Institute of Corrosion and the classification of workers in the corrosion field into research workers, specialists and general practitioners, on the lines of the medical profession; these were two suggestions made by Mr. C. L. Wilson at the 2nd Annual Dinner of the British Association of Corrosion Engineers held at the Waldorf Hotel on 26th January.

Developing the medical profession analogy, Mr. Wilson said that corrosion was a disease of industry and should be attacked as the medical profession attacks disease. The corrosion engineer, he said, was the G.P. of the profession. To find the answer to any problem he must have the backing of specialists and research workers. An engineer with a new project was like an expectant mother, said Mr. Wilson. But whereas an expectant mother was looked after by her G.P. throughout her pregnancy, the corrosion engineer was usually not called in until after the "child" was born; sometimes, in fact, not until it was many years old. Frequently, he was not called in until the structure was in danger of falling down, and was told to do something about it. Corrosion engineers should be called in to assist designers right from the initial stages.

The Institute of Corrosion was his own private idea, said Mr. Wilson. He thought that the three bodies concerned, the Corrosion Science Group led by Dr. T. P. Hoar, the corrosion group of the S.C.I., and B.A.C.E. should get together and form a body to correlate work and disseminate information. At the moment there was no way of getting information without contacting someone who had an axe to grind.

Spring Welding Meeting

THE 1961 spring meeting of the Institute of Welding will be held in London between 25th and 28th April, so as to coincide with the Engineering, Marine, Welding and Nuclear Energy Exhibition at Olympia. The theme of the meeting will be "Recent Developments in the Welding and Allied Processes." The fourth annual lecture, for which tickets are required, will be given at 7-30 p.m. on 24th or 25th April, by Dr. N. P. Inglis: the subject will be "Welding in the Non-Ferrous Field."

Light Metal Conference

THE fourth International Light Metal Conference to be held at Leoben, Austria, from 20th to 24th June, 1961, will have as its theme "Light Metals in Light Construction, in Architecture, and in Special Fields." The conference is being organised by The Montanistische Hochschule, Leoben, together with the Austrian light metal industry and enquiries concerning attendance should be addressed to: Geschäftsstelle der 4. Internationalen Leichtmetalltagung, Leoben/Stmk., Montanistische Hochschule, Österreich.

Cold Flow Forming Symposium

A TWO-DAY symposium on the subject of "Cold Flow Forming" will be held on Thursday and Friday, 9th and 10th March, 1961, at the Wolverhampton & Staffordshire College of Technology. Under the chairmanship of Mr. R. A. P. Morgan, O.B.E., superintendent of the Royal Ordnance Factory, Birtley, Co. Durham, papers on the following topics will be discussed: the cold extrusion of steel; the cold extrusion of metals under impact conditions; the replacement of forgings by cold flow forming; metallurgical aspects of cold flow forging; and tooling for cold flow forming. The fee for the course is £1 1 0, and further details may be obtained from the organisers, Messrs. G. R. Morton and H. Southan, at the college.

Symposium on Welding in Shipbuilding

A JOINT symposium on "Welding in Shipbuilding," sponsored by the Institute of Welding, the Royal Institution of Naval Architects, the North-East Coast Institution of Engineers and Shipbuilders, and the Institution of Engineers and Shipbuilders in Scotland, will be held in London in October/November, 1961. Eighteen offers of papers have already been accepted covering many aspects of the design of welded hulls, including the use of high yield point steels; aspects of construction, including a number on shipyard layout and the handling of materials, with others on the welding of the aluminium alloys; the non-destructive testing of welded joints; and the training and testing of ship welders. The symposium promises to be international in scope, contributions having already been promised from Belgium, Denmark, Holland, Italy and Sweden, while it is confidently expected that others will be forthcoming from Germany, Japan and the United States.

Lubrication Engineering Symposium

A SYMPOSIUM on "Lubrication Engineering," organised by the Institution of Plant Engineers, will be held in the Meeting Hall of the Institution of Mechanical Engineers on Thursday, 23rd March 1961. The four papers to be presented and discussed will be concerned with lubrication engineering in the petroleum, chemical, steel and plant manufacturing industries.

The symposium will be open to non-members of the Institution, the fee (including one set of pre-prints, morning coffee and afternoon tea) being £1 10 0. Further particulars may be obtained from the Secretary, The Institution of Plant Engineers, 2 Grosvenor Gardens, London S.W.1. (Sloane 0469).

United Steel Acquire G. R. Turner, Ltd.

THE United Steel Cos., Ltd., have acquired G. R. Turner, Ltd., of Langley Mill, Nottingham, for a price in the neighbourhood of £150,000. This old-established concern, situated about seven miles from Nottingham, will be controlled in future by United Steel Structural Co., Ltd., of Scunthorpe, a United Steel subsidiary. It will provide additional production capacity for the fabrication of structural steelwork, for which the

Structural Company has a full order book for many months ahead at the present time. Turner's employ about 120 workers, all of whom will be retained under the new ownership.

Personal News

BRIGHTSIDE ENGINEERING HOLDINGS, LTD., announce a number of changes in the boards of Graham Firth Steel Products, Ltd., Walsall, and Metal Mouldings, Ltd., London. MR. L. GRAHAM FIRTH has been elected chairman of the former company in succession to MR. E. H. KING, who retains his seat on the board. MR. A. R. LANCASHIRE has been appointed assistant managing director and MR. T. C. FIRTH and MR. R. I. SLATER have been elected directors. MR. N. G. WELCH and MR. B. J. Byrne have relinquished their seats on the board and MR. H. J. NASH has succeeded Mr. Byrne as secretary. MR. L. GRAHAM FIRTH has also been elected chairman of Metal Mouldings, Ltd., where he succeeds MR. N. G. WELCH who has resigned from the board. MR. R. I. SLATER has been elected a director and MISS E. M. YOUNG a special director.

MR. M. L. HACKETT has retired from his position as commercial manager of Dudley Drop Forging Co., Ltd., with which firm he has been associated in various executive capacities since 1940.

MR. W. G. J. APPLETON has been appointed a director of Stordy Engineering, Ltd.

THE British Electrical and Allied Industries Research Association announces that MR. L. GOSLAND has been appointed deputy director : he will continue to hold his position as research manager. MR. C. G. GARTON and MR. E. W. GOLDING become assistant directors whilst retaining their appointments as head of the materials department and head of the rural electrification department and overseas liaison officer, respectively. Following the retirement of MR. H. M. LACEY, DR. R. H. GOLDE has been appointed head of the surges and transformer department, with MR. M. WATERS as his deputy.

MR. ERIC N. SIMONS, for forty-one years editor of the *Edgar Allen News*, has retired after fifty years' service with Edgar Allen and Co., Ltd. Mr. Simons joined the company as office boy in 1911 and was appointed publicity manager in 1923—a position he occupied until September, 1959, when he was succeeded by Mr. A. B. Jordan.

AT the beginning of October the turbine factory at the Rugby Works of Associated Electrical Industries, Ltd., was incorporated in the A.E.I. heavy plant division. This factory and the adjacent buildings used for the manufacture and testing of large electrical machines have been re-named " Large Machine and Compressor Department." MR. J. D. RIDDLE, formerly manager of turbine factory, has been appointed manager of the new department, and MR. R. EVANS, formerly superintendent of large machine production in heavy plant factory, has been appointed assistant manager.

PHOTOELECTRONICS (M.O.M.), LTD., announce the appointment of MR. R. CARTER-PEDLER as sales manager of the company.

THE directors of Crofts (Engineers), Ltd., announce the appointment as sectional directors of MR. H. GOLDTHORPE, works director, MR. C. MASON, branch works director, MR. A. HEARN, production control director, and MR. S. W. BALL, foundry control director.

MR. D. W. PAYN, T.D., has resigned as general manager and secretary to the Lead Development Association and has taken up an appointment as secretary-designate to the London Master Builders' Association as from January 1st, 1961.

SAMUEL FOX AND CO., LTD., a subsidiary of The United Steel Cos., Ltd., announce that MR. R. D. POLLARD, director and chief metallurgist, has been appointed director of metallurgy. MR. R. WILCOCK, formerly works metallurgist, becomes chief metallurgist, responsible to the director of metallurgy for the management of the company's metallurgical department.

MR. J. C. COLQUHOUN has retired as chairman of The Manganese Bronze and Brass Co., Ltd., after occupying the position for twenty-eight years. MR. J. C. BUDD has been appointed to succeed Mr. Colquhoun as chairman and MR. R. D. POORE has been appointed a director.

THE board of The A.P.V. Co., Ltd., announce the appointment of MR. P. W. SELIGMAN as deputy-chairman. Mr. Seligman retains his position of managing director, and MR. H. P. N. BENSON has also been appointed managing director.

MR. L. A. K. HALCOMB, chairman and managing director of Kayser, Ellison and Co., Ltd., has retired from the position of managing director but is continuing as chairman of the company and remains on the board as consultant. He is also retaining his seat on the board of the parent company, Sanderson Kayser, Ltd. The new managing director of Kayser, Ellison and Co., Ltd., is MR. J. R. A. BULL, chairman and managing director of Sanderson Kayser, Ltd., and Sanderson Brothers and Newbould, Ltd.

MR. J. H. SELLARS, work study officer at United Coke and Chemicals Co., Ltd., has been appointed works manager (services), and MR. R. C. LIMB, who rejoined the company some months ago as assistant work study officer, is now work study manager.

MR. B. A. THURGOOD, after thirty-one years' service with George Cohen Sons and Co., Ltd., has been appointed resident director of George Cohen Australian Scrap Co. Pty., Ltd., Sydney. Mr. Thurgood was, until recently, George Cohen's branch manager in Morriston, near Swansea, South Wales.

Obituary

WE regret to record the tragic death of MR. E. F. WATSON, on Friday, December 30th, as a result of a road accident. Mr. Watson, aged 51, was a director of Efco Furnaces, Ltd., having joined the company—then called Electric Resistance Furnace Co., Ltd.—in 1933 after serving an apprenticeship in the heavy engineering works of John M. Henderson and Co., Ltd., of Aberdeen. Throughout his life he was intimately concerned with the development of electric resistance furnaces, and his work embraced both furnace design and sales promotion. He was for many years sales manager and was appointed to the board in 1955. His loss will be keenly felt both at home and overseas. In recent years he was a frequent visitor to the continent, where his long experience in furnace design and application was invaluable to other companies in the Efco Group.

RECENT DEVELOPMENTS

MATERIALS : PROCESSES : EQUIPMENT

Precision Flattening Machine for Blanked Components

THE Schubert WM2 precision flattening machine greatly improves the effectiveness of the blanking process and considerably enlarges its scope. Its use replaces manual flattening or the employment of planishing tools, operations requiring a skilled operator and a special tool for each type of component, respectively. Flattening is achieved in the machine by means of rollers, and the pressure is easily adjustable to lie in the narrow range between the elastic limit and the yield point of the material. Normally the flattening accuracy obtainable with two passes through the machine is 0·0008 in.

Working parts are housed within the frame of the machine in a floating mounting, which results in exceptionally quiet running. The motors drive distributor boxes through reduction gears and power is transmitted to the roller frame by shafts with universal joints. The flattening rollers are lapped and are supported by rolls mounted on needle beatings. All gears are hardened and profile-ground: the high-speed gears are mounted on ball bearings, and the slow-speed gears and flattening rollers on plain bearings.

Maintenance is confined to checking the oil levels in the drive, and lubricating the universal-joint shafts and the bearings of the flattening rollers. All parts of the machine subject to normal wear are readily replaceable.

Regulation of the machine is by four handwheels, and accurate setting is ensured by dial indicators. Once the correct setting for any workpiece has been determined it can be readily repeated. In a production run, all the operator is required to do is to feed the machine with workpieces. These should be more than 1 in. in length and less than 13$\frac{3}{4}$ in. in breadth; the thickness should be in the range $\frac{1}{32}$—$\frac{1}{4}$ in. Output, depending on the size of the workpiece, is 200 to 1,500 components an hour. The machine weighs 2,530 lb. and its power consumption is about 3/5 kW.

Vaughan Associates, Ltd., 4 Queen Street, Curzon Street, London, W.1.

Stainless Steel Electrode

A NEW electrode, Super Stainees, for cutting the cost of welding stainless steels is being produced by English Electric. It is claimed to weld faster and more easily than conventional stainless steel electrodes by depositing up to 50% more metal. This is achieved by using a heavier electrode coating containing metallic powder. It thus has the advantages of iron powder electrodes, and longer runs can be obtained with a single electrode. Super Stainees is used with the "touch" technique, and the lighter gauges are suitable for use in all positions: there is hardly any spatter and the slag is easily removed.

It can be used with a D.C. or A.C. output: the A.C. output should be over 70 V. open circuit, and with D.C. electrode positive is preferable.

English Electric Co., Ltd., Welding Electrode Division, Clayton-le-Moors, Accrington, Lancs.

Remote-Controlled Impact Tester

BECAUSE of the great amount of energy developed by heavy pendulum impact testers, Testing Machines, Inc., have developed what is claimed to be a completely safe model which is easy to operate. The new machine meets

the requirements of A.S.T.M. Method E-23 and is suitable for Izod, Charpy, and tension-impact tests. It has an automatic electric safety clutch brake, which stops

the pendulum after it has made one complete swing, a motorised pendulum return, and remote controls, thus saving time by speeding up the next test as well as making the operation safer.

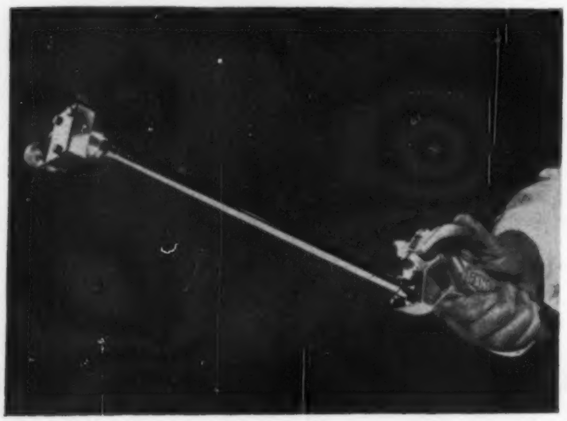
After the pendulum has been arrested, the electric motor, with gear head assembly, automatically raises the heavy pendulum hammer to its latched position and the machine is then ready for the next test. The control panel for operating the pendulum hammer can be located any distance from the machine for the safety of the operator or for other reasons. When testing materials which might shatter and throw fragments, the impact tester can be used with complete assurance that the operator is removed from the danger area. This machine is also well suited for testing radioactive or other dangerous materials. It is already in use in several laboratories where the control panel is located behind a protective wall to shield the operator. Because the operator does not have to lift the heavy pendulum after each test, a possible cause of bodily injury, strain is eliminated. Furthermore, the operator cannot be struck by the swinging pedulum during a test or in trying to reposition the pendulum.

Testing Machines, Inc., 72 Jericho Turnpike, Mineola, New York, U.S.A.

Hand Spray Gun for Cleaning and Lubricating Dies

A HAND SPRAY GUN introduced by the Foundry & Metallurgical Equipment Co., Ltd., has been designed specifically for use with pressure die casting machines and provides the operator with an air jet for cleaning the dies and an oil mist spray to give efficient lubrication. The air jet and oil spray are independently operated and are applied at right angles to the die faces to allow penetration into deep cavities. Positioning of the gun is facilitated by swivel-joint connections of the flexible air and oil hoses.

The gun can be supplied with a single-facing head for spraying one die at a time, or with a double-facing head for spraying both dies simultaneously. Each head carries a phosphor-bronze scraper blade for cleaning flash from the joint of the dies, and a suspension hook for hanging the gun between operations. The gun is fitted with stainless steel valves and has a single lever-action control giving immediate response. The density of the spray can be adjusted and then locked. The FAME hand



spray gun is available with tube lengths of 8 in., 12 in., and 18 in. It is supplied complete with 1 gal. oil container with filter and hinged lid, and two 6 ft. armoured hoses.

Foundry & Metallurgical Equipment Co., Ltd., Netherby, Queens Road, Weybridge, Surrey.

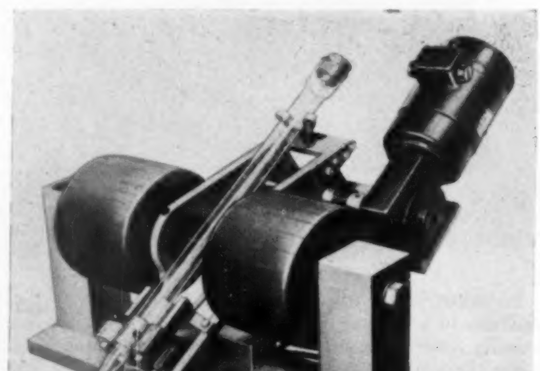
Analytical Reagents

ROBINSON BROTHERS, LTD., have recently issued a data sheet covering 1-4-di (carboxymethylthio) butane and 2-2′-di (carboxymethylthio) diethyl ether. These materials are now available in experimental quantities. It is suggested that they may be used as metal deactivators or sequestering agents where ethylene diamine tetra-acetic acid (E.D.T.A.) and its homologues are ineffective, especially in acid or non-aqueous media.

Robinson Brothers, Ltd., Ryders Green, West Bromwich.

Davis Magnetic Tube Tester

RAPID MAGNETIC, LTD., have the exclusive licence to manufacture the Davis magnetic tube tester. This unit is used for determining the magnetic content of ores and is particularly suitable for checking the efficiency of wet magnetic separators recovering magnetite and ferrosilicon in heavy media processes. The tube tester illustrated consists of an inclined glass tube set between the pointed poles of a powerful electro or permanent magnet. The ore sample is introduced into the water filled tube and agitated in such manner as to ensure



thorough washing of the arrested magnetics. The unit is continuously rated, having a power consumption of 230 watts, motor drive being 1/20 h.p.

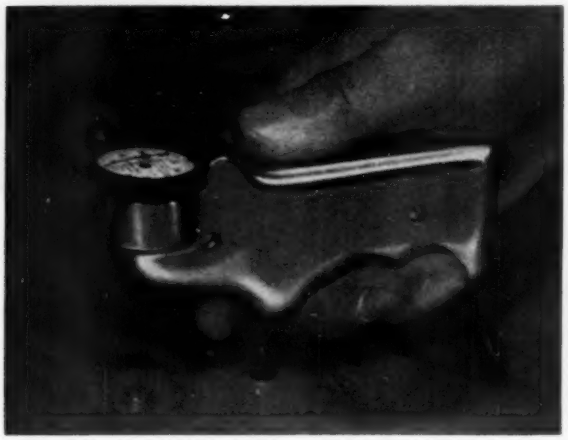
Rapid Magnetic, Ltd., Lombard Street, Birmingham, 12.

Portable Hardness Tester

THE new Barber-Colman Impressor hardness tester, distributed in the U.K. by Industrial Instrument Services Co., is a portable instrument available in three

models—one for plastics; one for metals such as aluminium alloys, brass and copper; and the third for extremely soft materials such as lead, linoleum, leather, etc. Simple in operation, it is only necessary to exert a light pressure against the instrument to drive the spring-loaded indenter into the material under test, the hardness reading being indicated on a dial divided into a hundred graduations.

The instrument indicates relative hardness rather than a specific hardness according to any of the recognised scales, although the reading can be approximately related to standard scales, as indicated in the available literature. It is believed that this instrument can serve a useful purpose in a wide variety of industries



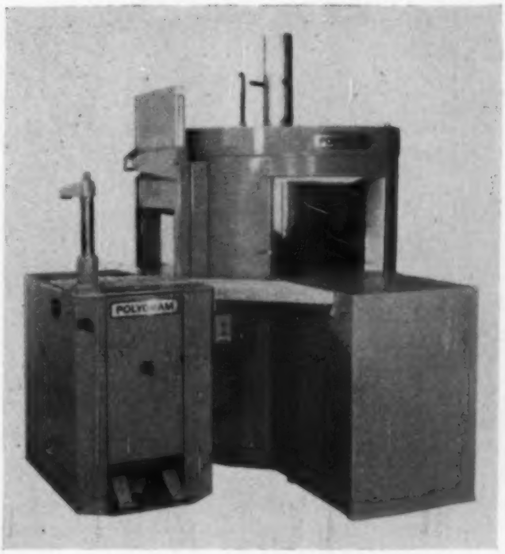
where a hand relative hardness tester can speed-up production and testing of materials and reduce rejects.

Industrial Instrument Services Co., Elkington Street, Aston, Birmingham, 6.

Shell Coremaker of Unit Construction

With the increased tendency to use shell cores in all types of foundries, the introduction of coremakers of unit construction is a logical step. The illustration shows how five basic units are bolted together to form the latest CMU shell coremaking unit by Polygram Casting Co., Ltd. The core blower can also be used alone where the foundry already has a suitable oven. Alternatively, the basic units (core blower, oven feed, oven, knock-out (ejection) table, and corebox return grid) can be connected in a different arrangement to suit any desired foundry layout.

When operated as shown, the basic units provide a complete coremaking installation with a single working level—so that there is no lifting of hot coreboxes which are transferred automatically into, through, and out of the oven. The cycle thus requires the core blower operator merely to slide the box from the knock-out table to the 1½ in. diameter blowing orifice. Automatic pneumatic clamping, blowing with a fluidised column of moulding material, and unclamping, follow in rapid succession—an interlock preventing blowing prior to the box being clamped. The operator then pushes the invested box across to the pneumatic transfer arm which pushes it into the oven whilst the door is simultaneously



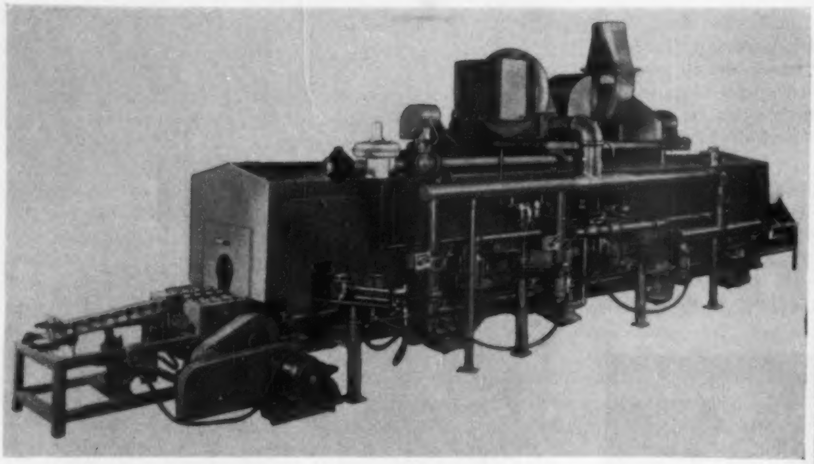
raised. On its way to the transfer arm, the box passes over a grid through which any surplus moulding material drops by gravity to leave a hollow shell core. Whilst the box is passing automatically into the oven, the operator repeats the investment cycle with the next core box. The investment time, normally of 10–15 seconds, thus controls the overall output of the machine—enabling the maximum potential output of cores to be approached. For lower outputs, one operator can both blow cores and strip them from the box; quick-acting stripping gear can be fitted where necessary to the standard knock-out table.

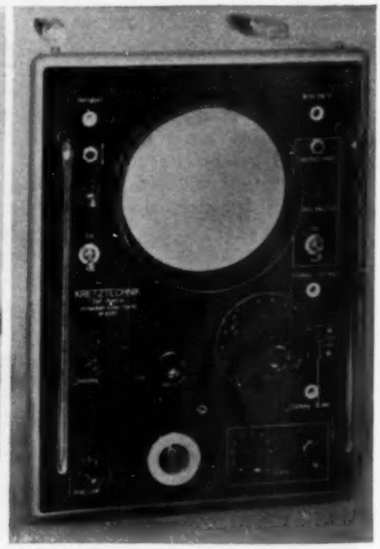
The rotational speed of the oven table can be adjusted to provide the optimum curing time for the cores concerned. Additional flexibility is given by precise thermostatic control of the oven, which can be heated optionally by electricity, town gas, propane or butane. Efficient thermal insulation is provided to save fuel and ensure good working conditions. A conveniently positioned lever enables the operator to return surplus moulding material through a valve without opening up the main container. This container in fact holds about 50 lb. of moulding material when full, and can be provided with automatic topping-up where justified by production requirements. The pneumatic clamp adjusts itself automatically to all shapes and sizes of corebox up to a maximum height of 15 in. Thus, even the wide diversity of components encountered in a jobbing foundry can be handled simultaneously on the new equipment.

Polygram Casting Co., Ltd., Shernfold Park, Frant, Tunbridge Wells, Kent.

Rapid-Heating Furnace for Light Alloy Billets

By an agreement with Granco Inc., U.S.A., A.E.I.-Birlec, Ltd., can now offer to Great Britain, Europe and the Commonwealth countries the Granco gas-fired rapid billet furnace. This furnace is used extensively throughout America and many outstanding features are claimed for it. It has extremely rapid contact flame heating and is built in a range of sizes for billets up to 18 in. diameter





and of any length. Billet diameter can be varied widely without the need for furnace adjustment or parts change, and electronically-operated automatic temperature controlling devices are incorporated.

The combination of speed and economy afforded by the Birlec-Granco furnace is particularly suited for heating light alloy extrusion billets, heating rates of the order of 1 in. diameter per minute being obtained with aluminium. Rapid contact heating means uniform metal temperature—no hot or cold spots in the metal, and no cold end billets—resulting in good metal at the die.

The minimum of maintenance is required and running costs are said to be extremely low. The Birlec-Granco furnace is adaptable to any press: it occupies very little floor space and can be equipped with automatic billet loading and transfer mechanisms to make an ideal shop layout.

A.E.I.-Birlec, Ltd., Tyburn Road, Erdington, Birmingham 24.

High Resolution Ultrasonic Thickness Measuring Equipment

AVELEY ELECTRIC, LTD., have introduced into the U.K. the new Kretz Series 6,000 ultrasonic thickness testing instrument. The equipment, which incorporates a high stability wide band amplifier having a frequency range of 3 Mc./s.–20Mc./s., has been specially designed to include facilities for the accurate measurement of dilation or contraction, and a special triggering circuit to give warning when a pre-determined limit of measurement has been reached.

Thickness measurements are accurately obtained by spanning several pulses with a movable pedestal whose leading edge can be moved to divide the first cycle of each ringing pulse. The higher the number of echo-pulses used for measurement, the greater the discrimination obtained. The vertical deflection response of the trace is better than 0·05 micro-seconds so that an echo-time discrimination of 0·0125 micro-seconds is obtained.

The unit has an effective depth range from 1 cm. to 70 cm. for flaw detection, and for thickness gauging a maximum range of 20 mm., dependent on frequency and attenuation of the material under test. The power consumption is 180 VA. A low voltage socket is provided for certain types of work where stringent electricity safety precautions are essential. The use of this socket automatically makes the high voltage connection inoperative.

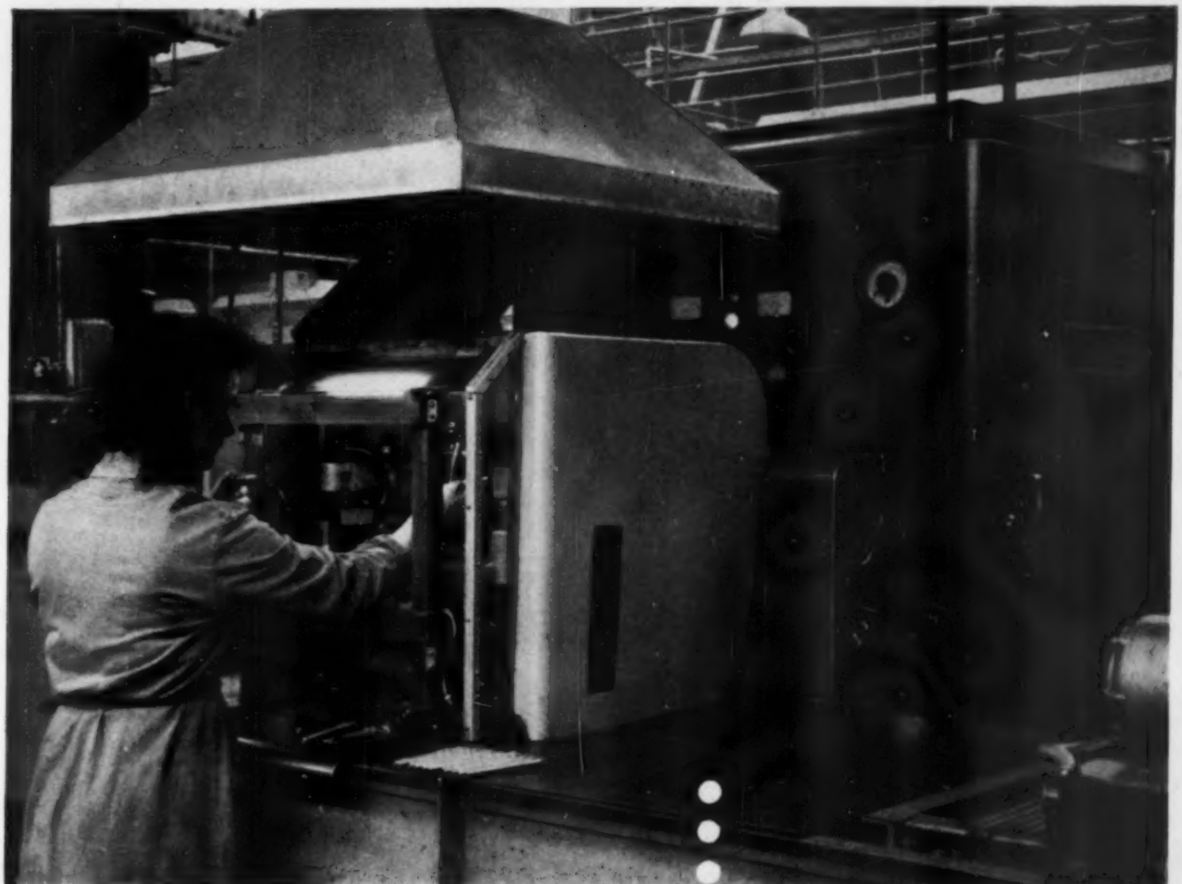
Aveley Electric, Ltd., Ayron Road, Aveley Industrial Estate, South Ockendon, Essex.

Filtration of Spark Erosion Machine Dielectric

SPARK erosion is a process used in connection with the machining of " difficult " alloys. The function of spark erosion is to vaporise the metal by a high frequency discharge, each spark vaporising a fragment of metal while it is immersed in a dielectric, usually paraffin or transformer oil. The performance of the machine depends upon the absolute cleanliness of the dielectric liquid, and in this connection Stream-Line Filters, Ltd., have been working in close liaison with the manufacturers: their latest filter design is a unit which, it is claimed, ensures the complete removal of all the eroded particles.

This new filtration unit incorporates a Stream-Line filter which embodies the principle of their well-known edge filtration. The construction of the unit is arranged so that filtration can be either continuous or in batches according to requirement. For continuous filtration, the unit is coupled directly into the spark erosion oil line in a closed circuit, and the dirty liquid flows into the filter, where it is cleaned and returned to the machine. For batch filtration, there are two 20-gallon tanks, the dirty one in the front and the clean one at the back, each with a separate motor-driven pump. The liquid in the dirty tank passes through the filter and flows into the clean tank ready for transferring to the spark erosion machine. Valves and cocks in the piping circuit make it easy for the required filtration system to be brought into operation. A suitable metal drawer is situated at the base of the filter to catch the sludge when the filter is cleaned by blowing compressed air through the packs in the reverse direction.

Stream-Line Filters, Ltd., Vokes Group, Henley Park, Guildford, Surrey.

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Stereoscopic Microradiography

By W. M. Williams, M.Sc.

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The principles of stereoscopic microradiography are discussed and the distinctive advantages of the method are outlined. Examples of its application to the radiographic examination of metallurgical microstructures are illustrated by stereo pairs. The method may also be used for quantitative examination of microstructural features; the morphology of a single grain from a polycrystalline aluminium alloy is examined by way of illustration.

MICRORADIOGRAPHY, a term which covers any method that permits a detailed radiographic examination of a specimen, is not a new technique. Heycock and Neville[1] before 1900 were among its early practitioners, and the method has been used ever since on a relatively small scale as an offshoot of optical micrography. The experimental arrangement (Fig. 1) is simple, and now that fine focus X-ray tubes and fine-grained photographic emulsions are available, the peculiar advantages of microradiography can be more widely exploited.

The following sections deal with the extension of ordinary microradiography to three dimensions. Stereoscopic microradiography requires two exposures, the specimen and photographic plate being turned through a small angle between exposures. The subsequent enlargements are viewed in a stereoscope, and the microstructure is revealed in three dimensions without any of the confusing overlapping that occurs in ordinary microradiographs. The distribution, shapes and sizes of particles, flaws and interfaces can be observed in perspective; measurement of distances, areas and angles presents little difficulty. Stereoscopic microradiography, which has been used in few investigations to date, has many advantages over two-dimensional microradiography:

(1) The microstructure of opaque materials is rendered visible in three dimensions without the necessity for special polishing and etching treatments.

(2) Quantitative measurements may be made.

(3) A knowledge of the relationship between microstructure and the dihedral angle between the phases present in an alloy permits the preparation of specimens designed for the investigation of special problems.[2]

(4) A sample can be observed after successive treatments so that a process, such as corrosion or crack propagation, can be studied in a completely quantitative way.

*Now Assistant Professor, Department of Metallurgical Engineering, McGill University Montreal.

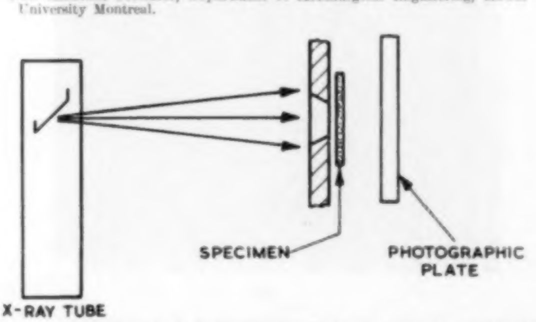


Fig. 1.—Experimental arrangement for microradiography

Principles of Microradiography

Choice of X-ray Conditions

The decrease in intensity of a beam of monochromatic X-rays traversing a specimen of thickness x is given by Lambert's Law of Absorption:

$$I = I_0 e^{-\mu x}$$

where I_0 is the intensity of the incident beam, I the intensity of the emergent beam and μ the linear absorption coefficient of the material at the X-ray wavelength employed (Fig. 2*a*).

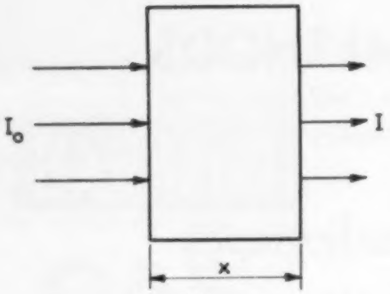
If the X-ray beam encounters an inhomogeneity (for example a particle of a second phase), then the emergent intensity of the beam from that region will be different from that part of the beam which has passed through the matrix only, and a film placed behind the specimen will register the different intensities from the two regions (Fig. 2*b*).

The ratio of the two intensities is given by

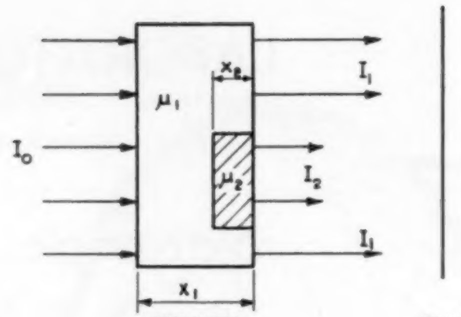
$$\frac{I_1}{I_2} = e^{-(\mu_1-\mu_2)x_2}$$

where x_2 is the thickness of the second phase material and μ_1 and μ_2 are the linear absorption coefficients of the matrix and second phase, respectively.

For a given photographic emulsion, an improvement in contrast occurs if the ratio I_1/I_2 is made as large as possible. Thus $(\mu_1-\mu_2)$ must be as large as possible. This objective can be attained in two different ways: (*a*) by using long wavelength radiation; or (*b*) by taking



(a)



(b)

Fig. 2.—(a) Absorption of X-rays by a homogeneous substance ; (b) the radiography of a composite specimen.

advantage of the abrupt discontinuities (the absorption edges) in the absorption *vs.* wavelength curves for the elements in the sample.

(a) Use of Long Wavelength X-Rays

The linear absorption coefficient μ of an element varies with the wavelength λ according to the relation

$$\mu = KZ^4\lambda^3 \quad \dots\dots\dots\dots\dots\dots \quad (1)$$

where Z is the atomic number of the absorber. K is a constant for a particular element over a range of wavelengths and then changes abruptly at the absorption edges (Fig. 4).

In the composite specimen of Fig. 2*b*

$$\mu_1 = K_1Z_1^4\lambda^3$$

$$\mu_2 = K_2Z_2^4\lambda^3$$

Hence $\quad \mu_1 - \mu_2 = \lambda^3(K_1Z_1^4 - K_2Z_2^4)$

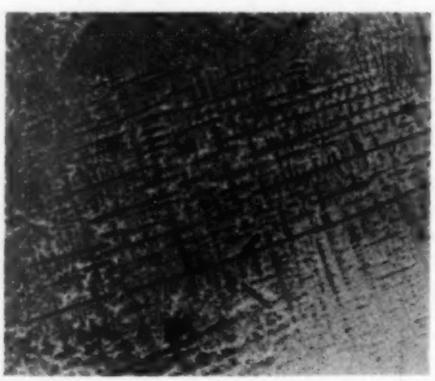
Thus, the value of $(\mu_1 - u_2)$, which controls film contrast, increases rapidly with wavelength. This rule—" the longer the wavelength the better the contrast "—is a good general guide to microradiographic procedure. Fig. 3*a* and 3*b* are microradiographs of a thin section of cast leaded bronze, taken at 47 kV. and 17 kV., respectively. The distinction between copper-rich and tin-rich areas in the specimen, as well as variation in specimen thickness, is much more marked in Fig. 3*b*.

(b) The Absorption Edge Method

If the elements in the sample are of similar atomic number, the difference between the absorption coefficients $(\mu_1 - \mu_2)$ may be too small to give good contrast even with the longest wavelengths that can be conveniently employed. However, as Clark pointed out,[3–5] it is possible to improve the contrast considerably by using suitable monochromatic radiation. The principle of the method as applied to a specimen containing copper and iron may be understood from Fig. 4, which shows the variation of absorption coefficient with wavelength for these two elements.

The discontinuities in the curves of Fig. 4 are the K absorption edges and correspond to the K-shells of the copper and iron atoms respectively. It is clear that the difference between the absorption coefficients is small (even at long wavelengths) except in the region between the absorption edges. Thus, the best choice of X-ray wavelength is one that lies between the absorption edges for copper and iron. Filtered radiation from a copper anode is a suitable choice. Fig. 5*a* shows an enlarged microradiograph of a sample of cast copper–5% iron, in which the dendritic structure and undissolved particles of iron are clearly revealed. A comparison of this figure with Fig. 5*b*, which shows the same area taken with continuous radiation, demonstrates

(a)



(b)

Fig. 3.—(a) Microradiograph of leaded bronze, W radiation, 47 kV. (peak wavelength 0·5 Angstrom) ; (b) same area as (a), W radiation, 17 kV. (peak wavelength 0·8 Angstrom). × 30

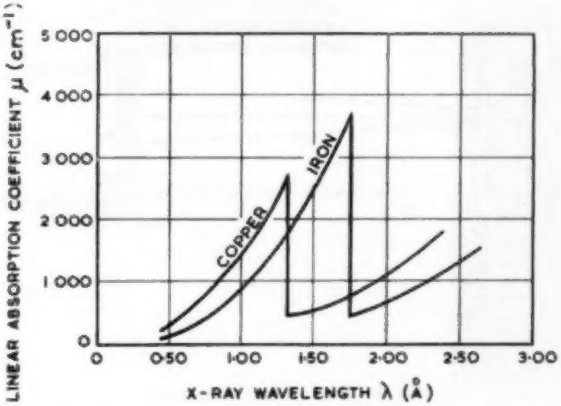


Fig. 4.—Variation of absorption coefficient with X-ray wavelength.

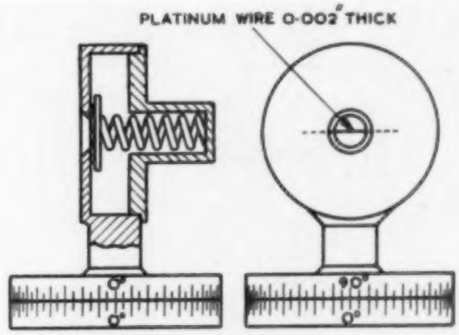


Fig. 6.—Camera for microradiography (approx. half size).

the superiority of the absorption edge method in this case.

For most metallurgical specimens, however, the radiation from a tungsten target operated at a voltage between 10 and 50 kV. provides adequate contrast. The use of monochromatic radiation may be restricted to cases where maximum contrast is essential, as with copper-zinc alloys,[6] or when an attempt is being made to identify a constituent by making several exposures with different wavelengths. The occurrence and distribution of manganese sulphide in steel has been studied in this way [7,8].

The Geometry of the Arrangement

There are two ways of producing an enlarged radiographic image of a specimen: (*i*) by placing the photographic emulsion some distance behind the specimen, in which case the magnification depends on the distances of the emulsion and specimen from the X-ray focus; or (*ii*) by placing the emulsion immediately behind and in contact with the specimen and enlarging the image photographically.

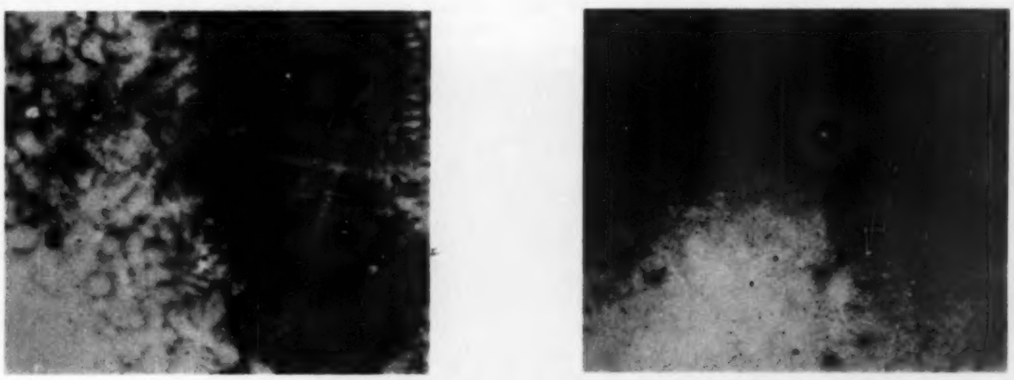
The first method demands an extremely small X-ray focal spot if useful magnifications are to be achieved, and it is because of this experimental difficulty that the method has not been widely used. Cosslett and Nixon[9,10] in their "X-ray shadow microscope" have produced X-ray focal spots as small as 0·0001 cm. in diameter and with this apparatus it is possible to obtain direct magnifications of more than 100×.

The second method of making a microradiograph, by placing the photographic emulsion in contact with the specimen and subsequently enlarging photographically, is the one commonly used. Using this arrangement, the definition obtainable with the focal spot of an ordinary diffraction tube is excellent and enlargement of the microradiograph is mainly limited by the grain size of the emulsion.

Experimental Details of Microradiography

The Camera

The camera shown in Fig. 6 consists of a metal box with a closely-fitting lid. The specimen covers the aperture in the front of the camera and the microradiograph is registered on a piece of fine-grained photographic plate pressed against the back of the specimen with a light spring. The camera may be mounted on a graduated base so that it can be turned through a small angle for taking stereoscopic microradiographs. The radiographic shadow of a thin wire stretched horizontally across the aperture is useful for orienting microradiographs for stereoscopic examination.



(a) (b)

Fig. 5.—(a) Copper–5% iron specimen, Cu K_α radiation; (b) same area as (a), tungsten radiation. × 30

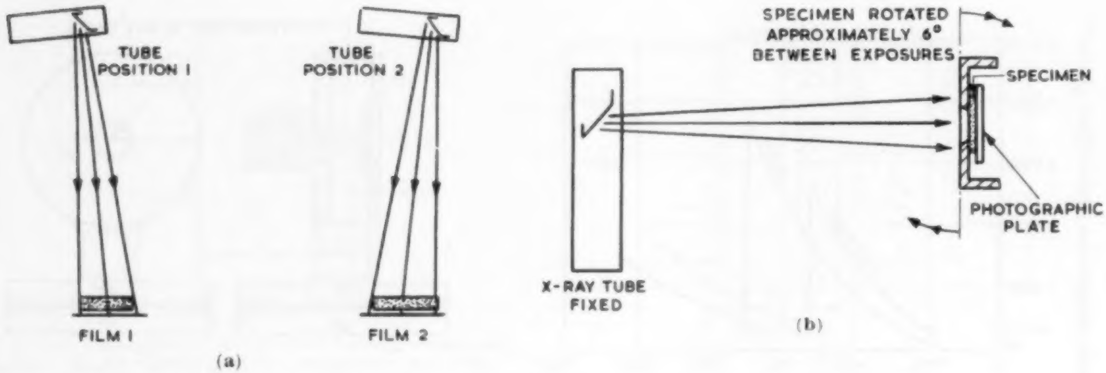


Fig. 7.—(a) Making a stereoscopic pair of radiographs ; (b) stereoscopic microradiography.

Preparation of the Specimen

A specimen for two-dimensional microradiographic examination must be thin for two reasons : (*i*) exposure times increase rapidly with thickness ; and (*ii*) if the specimen is much thicker than 0·01 cm., confusion arises from the registration on the microradiograph of overlapping features. Clark[5] recommends 0·003 in. for steel samples and up to 0·010 in. for magnesium. Specimens for stereoscopic examination on the other hand can be much thicker (up to 0·2 cm. for light alloys) since any apparent confusion in the pair of microradiographs is eliminated when they are viewed stereoscopically.

A specimen with parallel faces is conveniently prepared by machining to a thickness of approximately 0·2 cm. and then hand-grinding it to the final thickness, finishing with 4/0 grade emery paper. Specimens are easy to handle if they are mounted on a microscope slide with Canada balsam or double-sided adhesive tape.

Photographic Procedure

The small unmagnified image obtained in contact microradiography requires considerable enlargement, so that a fine-grained emulsion is essential. Eastman Type 649–0 spectrographic plates are extremely fine-grained and can be enlarged up to 750 ×. Eastman Type 548–0 and Ilford High Resolution Plates are faster and may be enlarged up to 200 × or 300 ×. Developing solution D19 is suitable and the development time may be from 1 to 10 min., depending on the contrast required.

Fine-grained emulsions are extremely slow, and it is often worthwhile in preliminary work to sacrifice definition and use a faster emulsion. Small pieces of lantern slide are very useful for this purpose.

Stereo-Microradiography

Method

In order to obtain a stereoscopic pair of microradiographs, it is necessary to record the X-ray shadows of the specimen from two slightly different viewpoints. The usual procedure in industrial or medical radiography is to keep the subject in the same position and move the X-ray tube a few inches between the two exposures (Fig. 7*a*). The two radiographs are then viewed in a stereoscope. The amount of movement necessary between exposures clearly depends on the degree of perspective required.

In microradiography, where the specimen and its mounting are small, it is more convenient to turn the specimen and photographic plate through a small angle between the two exposures and leave the X-ray tube in the same position (Fig. 7*b*). An angle of rotation of 4°–10°, depending on the thickness of the specimen and the degree of perspective required, provides a good sense of depth in the subsequent enlargements.

Some Examples of Stereo-Microradiography

Fig. 8 is a stereo pair showing the spatial arrangement of lead particles in a free-machining brass. Fig. 9 shows the shape and distribution of needles of $TiAl_3$ in a cast

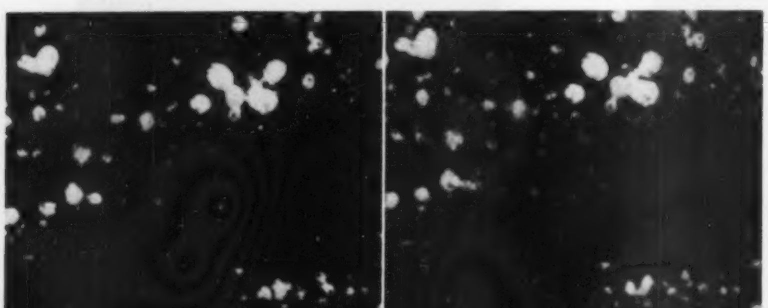


Fig. 8.—Distribution of lead particles in free-cutting brass. × 50

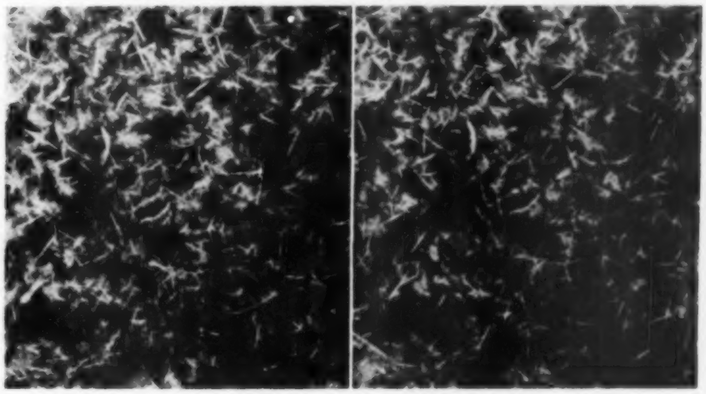


Fig. 9.—Plates of $TiAl_3$ in cast aluminium-titanium alloy. × 40

aluminium-titanium alloy. With a little practice, such stereo pairs may be viewed without optical aids by allowing the eye directions to drift apart until the right-hand picture seen with the right eye fuses with the left-hand picture seen with the left eye. For prolonged viewing of larger prints, a simple stereoscope is necessary.

Fig. 10 is a stereo pair of a zinc-tin alloy which was cast, rolled and recrystallised at 350° C. At this temperature, the liquid tin-rich phase has spread along the edges of the zinc grains outlining every grain and making the arrangement of grain faces, edges and corners visible in three dimensions. The tendency of a second phase to be distributed as continuous prisms along grain edges or as isolated particles at grain corners, or to spread over grain faces, is governed by the " dihedral angle " of the second phase relative to the matrix. This relationship between dihedral angle and the microstructure of metals, which has given metallurgists a rational basis for the interpretation of microstructure, was first pointed out by Smith in 1948.[11]

The production of specimens similar to the one shown in Fig. 10 (dihedral angle approx. 55°) is of particular importance. In conjunction with stereo-microradiography such specimens can be used in studies of plastic deformation, recrystallisation, grain growth and transformations. It is thus possible to carry out a metallurgical process and to follow the changes three-dimensionally and non-destructively.

Measurement of Depths, Angles, Areas

For many investigations, a clear three-dimensional view of microstructure is all that is needed in order to examine the shapes, sizes and distribution of internal features. However actual measurement of distances and angles presents no great difficulty.

The position of an internal feature can be easily determined from parallax measurements on the two microradiographs. Two marks a and b on the front and back surfaces of the specimen define its thickness (Fig. 11a). Suitable markers, in the absence of any natural surface features which would show up on the microradiographs, could be two spots of lead paint or two fine scratches. Fig. 11b shows the appearance of the corresponding microradiographs.

The depth d of the point F, measured vertically downwards from the marker A is given by

$$d = \frac{\text{Parallax between } A \text{ and } F}{\text{Parallax between } A \text{ and } B} \times \text{Specimen Thickness}$$

$$= \frac{A_2F_2 - A_1F_1}{A_2B_2 - A_1B_1} \times D \qquad (2)$$

where D is the specimen thickness.

The positions of internal features, such as particles, grain corners or gas pockets, may be easily determined from equation (2) and an example is taken from Fig. 12.

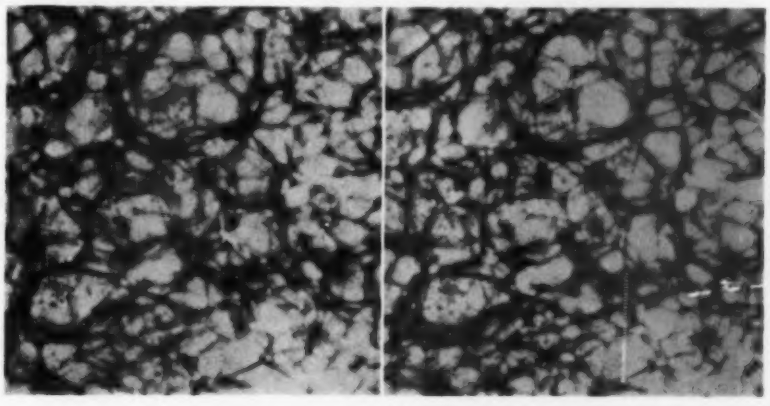


Fig. 10.—Grain structure in annealed zinc-5% tin. × 30

Fig. 11.—(a) Stereo-microradiography of a specimen with two surface markers A and B; (b) the corresponding microradiographs showing the images of the two markers and a small internal feature F.

which is a pair of stereoscopic microradiographs of an annealed aluminium-tin alloy. The grains are made visible by the continuous network of tin along the grain edges.

A large grain in the interior of the specimen was chosen for examination (Fig. 13) and parallax measurements were made on all the twenty-six vertices in both microradiographs, using a bench microscope and calibrated eyepiece. The parallax was measured with reference to grain corner 1, which was the corner furthest away from the specimen surface. The total parallax measurement over the 1 mm. thick specimen was 0·075 mm. The differences in height between corner 1 and every other corner were calculated from equation (2) and the values are shown in Table I.

The distances between grain corners (as seen in projection on the microradiographs) were also measured on both microradiographs and the averages taken as the true projected distances. These distances, together

TABLE I.—DIFFERENCES IN HEIGHT BETWEEN GRAIN CORNER 1 AND THE OTHER 25 CORNERS OF THE GRAIN SHOWN IN FIG. 13, CALCULATED FROM PARALLAX MEASUREMENTS

Pair of Grain Corners	Parallax between Grain Corners (mm.)	Difference in Height between Grain Corners (mm.)	Pair of Grain Corners	Parallax between Grain Corners (mm.)	Difference in Height between Grain Corners (mm.)
1–2	0·026	0·35	1–14	0·012	0·16
1–3	0·029	0·39	1–15	0·021	0·28
1–4	0·034	0·45	1–16	0·021	0·28
1–5	0·031	0·41	1–17	0·023	0·31
1–6	0·025	0·33	1–18	0·017	0·23
1–7	0·025	0·33	1–19	0·008	0·11
1–8	0·030	0·40	1–20	0·015	0·20
1–9	0·021	0·28	1–21	0·002	0·03
1–10	0·025	0·33	1–22	0·001	0·01
1–11	0·014	0·19	1–23	0·001	0·01
1–12	0·019	0·25	1–24	0·008	0·11
1–13	0·013	0·17	1–25	0·013	0·17
			1–26	0·012	0·16

Total parallax over 1 mm. thick specimen—0·075 mm.

with the height differences given in Table I, completely determine the geometry of the grain; it is drawn to scale in Fig. 13.

An internal angle such as BAC (Fig. 14) can be calculated from the expression

$$\cos\theta = \frac{x_1 x_2 \cos\alpha + y_1 y_2}{[(x_1^2 + y_1^2)(x_2^2 + y_2^2)]}$$

where x_1 and x_2 are the projected lengths of AB and AC and α is the included angle (all measured directly on the microradiographs). The differences in height between A and the points B and C are y_1 and y_2 and may be calculated from the parallax as already described.

The three vertex angles at grain corner 5, for example, calculated from the information given in Fig. 13, turn out to be 110½°, 114° and 111½°. The theoretical value[12]

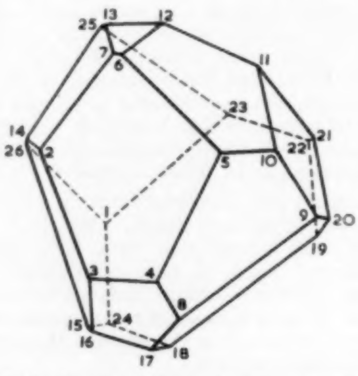


Fig. 13.—Grain in aluminium-tin alloy (see Table I for dimensions normal to diagram). × 200

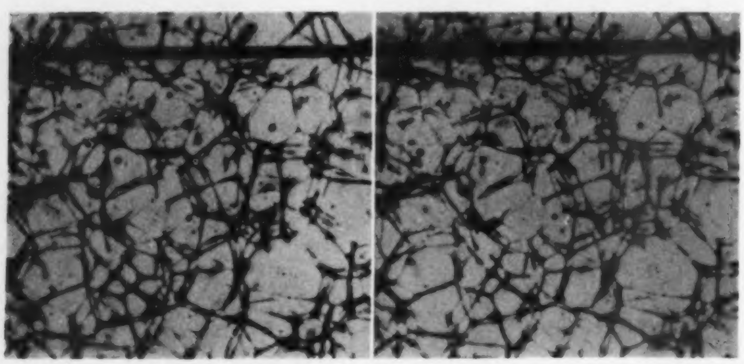


Fig. 12.—Grain structure in aluminium-tin alloy. Grain near the centre illustrated in Fig. 13.

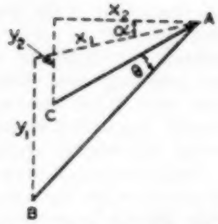


Fig. 14.—Calculation of an internal angle.

for well-annealed grains (as for soap bubbles) is $109\frac{1}{2}°$. The discrepancies can be explained by the slight curvatures of the grain edges which have been ignored in drawing Fig. 13.

The determination of area, which might find application in grain boundary studies, follows from a knowledge of distances and angles.

Acknowledgments

The writer would like to acknowledge his indebtedness to Dr. C. S. Smith, Institute for the Study of Metals, University of Chicago, who suggested using stereoscopic microradiography for the investigation of the shapes of metal grains.[2] The provision of laboratory facilities and the arrangement of a research fellowship by Dr. L. M. Pidgeon, Department of Metallurgical Engineering, University of Toronto, are also gratefully acknowledged.

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Polishing With Diamond Powder

New Applicator Eliminates Waste

WHEN a card-player talks of diamonds he refers to a suit; when a lady mentions them she is thinking of the precious stone; but when—as is happening more and more often these days—an engineer or a metallurgist uses the word, he means one of the hardest cutting materials known to man. In this context the material is used in powder form, whether bonded to form grinding or slitting wheels, or compounded with a vehicle to produce a lapping or polishing material. The optical properties of the diamond are of no importance in such applications; what does matter is the effectiveness with which the particles maintain the sharpness of their cutting points and resist crushing under operating pressures.

Since the days of Leonardo da Vinci (1485) diamond dust—usually suspended in olive oil—has been used for polishing precious or semi-precious stones, but only recently have methods of accurate sizing, followed by even distribution and permanent suspension, been discovered. With this discovery has come a widening of the scope of diamond lapping compounds and they are currently used to impart the highest degree of finish to plastic moulds, tungsten carbide dies for metal working, tungsten carbide rolls, calender rolls, cutting tools, die casting cavities, instrument bearings and pivots, semiconductors, and metallurgical and geological specimens. The hardness of the diamond particles make them suitable for use on the hardest materials for fine grinding, lapping and polishing.

In all these applications, and nowhere more than in metallurgical specimen polishing, uniform size and even distribution of the particles in the suspension are vital factors. At the Maidstone works of Engis, Ltd.—specialists in the production of diamond compounds for precision finishing—new methods have been devised by which uniform distribution and permanent suspension at all temperatures can be guaranteed. The Hyprez compounds marketed by Engis, Ltd., range in particle size from 0·1 to 90 micron, the twelve grades being distinctively coloured for easy identification. They are available in a range of concentrations and in oil- and water-soluble forms. Every batch is examined microscopically before sale, accurate counts being made to ensure that the average size of particles is within the required limits, and that smaller and larger particles are so few that scratching or uneven cutting of the workpiece cannot occur: the actual count for each batch is recorded.

Without doubt the use of diamond compounds in the polishing of metallurgical specimens for microscopic examination has led to greatly improved results. The cleaner cutting action of diamond abrasives prevents surface constituents in the metal from being disturbed, and the diamond polishing technique is particularly suitable where hard and soft constituents are present, and where it is necessary to examine the junction between two areas of different hardness, such as, for example, soft solder and the parent metal. Despite the comparatively high cost of these compounds, the

The new Hypl'cator.

small amount used and the rapidity with which satisfactory polishes are achieved more than offset this drawback. Nevertheless, the compounds are too expensive to waste, and metallurgists and other users will welcome the new micrometer-controlled syringe, known as the Hyplicator, which Engis have recently introduced for the accurate metering of Hyprez compounds.

To eliminate the possibility of damage to the article being polished by corrosion products such as crystalline copper sulphate or verdigris, which could result from the use of a metal applicator gun, the body of the Hyplicator is made of moulded nylon, with a threaded nylon shaft which engages with a knurled nylon micrometer screw wheel in the top of the barrel. The shaft is connected to a neoprene plunger, so that when the knurled thumb wheel is revolved the plunger moves down the barrel to dispense the requisite amount of compound. The plunger base has a greater radius of curvature than the nozzle cup into which it descends, so as to ensure that every vestige of compound is forced into the centre of the cup and down the nozzle as the syringe empties. The whole nozzle fitting can be removed and attached to a freshly loaded syringe (same grade of compound, of course) so that none of the compound is wasted. The Hyplicator, which is completely expendable, has been specially designed for single hand operation ; although its mode of operation is completely different from that of the push-type syringe, as will have been noted earlier.

Diamond compounds are used at nuclear research establishments for grinding and finishing titanium, zirconium, tantalum and other rare metals, including beryllium, whose highly toxic dust makes it necessary to machine the material by remote control in a totally enclosed cabinet. Under these conditions the compound can be metered on to the work by means of an electric motor with a rubber driving wheel which bears on the knurled screw in the top of the Hyplicator.

There is another reason for welcoming any means of avoiding waste, apart from the question of cost: today some 18 million carats of diamond are mined annually to meet a total world demand for 25 million carats. A proportion of industrial quality diamond comes from the Congo and other parts of Africa where labour or political difficulties may lead to a fall in output. But the demand for diamonds is steadily growing, and there is, therefore, a real need to avoid waste by haphazard application of these substances. Meanwhile, Engis, Ltd., are already experimenting with special techniques to enable them to produce equally effective compounds from artificial diamonds. There is little doubt, however, that the new Hyplicator will become an increasingly important tool throughout industry during the years to come.

The Physical Society Exhibition

ANYONE with shares in concerns manufacturing string or sealing wax must have come away from the 1961 Physical Society Exhibition* in a thoughtful mood, for it appears that such materials no longer play the important part in the making of scientific apparatus that once they did. On the other hand, anyone with vested interests in black boxes . . . In spite of the modern tendency to hide away the interesting parts of a piece of apparatus in a well-designed and dust-excluding case, the display put on this year was full of interest for the large number of visitors, in fact, even in a single field such as metallurgy the visitor with general interests found himself with too little time to see all that he would like to see in a single visit. In the course of the next few months we hope to refer to some of the exhibits of metallurgical interest in a little more detail than would be possible in a single issue.

Measurement of Strip Speed

The continuous measurement of the reduction in gauge in the temper rolling of strip is still an unsolved problem. One approach is to compare the speeds of the strip before and after rolling ; the increase in speed is, of course, directly proportional to the percentage reduction in gauge. Magnetic methods of measuring strip speeds have been tried but were found too sensitive to up-and-down movement of the strip in the neighbourhood of the measuring instruments. The British Iron and Steel Research Association is now developing a new method in which two photocells are sited on two illuminated spots on the strip surface, the two spots being a fixed distance apart and lying along the pass-line. Small irregularities in the light reflected from the strip surface give rise to a pattern in the output of the first photocell. After an interval of time, depending on the distance apart of the two photocells and the strip speed, another similar pattern appears in the second photocell. Thus, if the output of the first photocell is delayed (e.g. on a tape recorder) and then added to the second photocell signal, a maximum combined output will be obtained when the delay time introduced is equal to the time for passage of a point on the strip surface between the two photocells. From this delay time, and the known distance between the illuminated spots, the strip speed can be readily calculated.

Portable Potentiometer

The Cambridge Instrument Company's new potentiometer is fitted with a built-in galvanometer, standard cell, and batteries for potentiometer current and for the potential source. It has a single range extending from 0·05 mV. to 101·05 mV., and is designed for testing thermocouples and associated indicators, recorders and controllers. Potential is selected by a switch giving 100 steps of 1 mV. each and a slidewire calibrated between 0·05 mV. and 1·05 mV. These give a discrimination of 0·01 mV. The accuracy is 0·1% or half a slidewire division, whichever is the greater. The function switch can be set so that the instrument will measure potential in either of two external test circuits, connect the auxiliary potential source to the test terminals for energising deflectional indicators being tested, and disconnect the internal galvanometer, so enabling the potentiometer to be used directly as a calibrated voltage source for testing self-balancing potentiometric recorders or other non-current-consuming devices. Terminals for connecting a sensitive reflecting galvanometer are provided for applications where greater sensitivity is required than that which can be obtained with the built-in pointer galvanometer. The current drain from the potentiometer battery is so small that re-standardisation is required only at infrequent intervals.

* Following the union between The Physical Society and The Institute of Physics, the official title is now The Annual Exhibition of the Institute of Physics and The Physical Society but it will no doubt continue to be referred to as The Physical Society Exhibition as it has been for so long.

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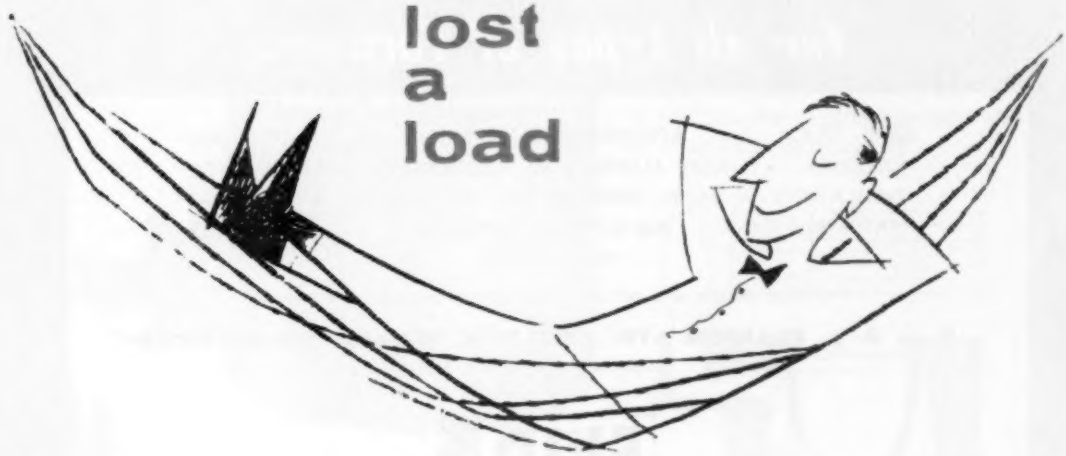

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worries

(Hargreaves did) . . . . the day he sent for his copy of the HYPREZ book, and also received details of the new slow speed lapping machine and new HYPROCEL self adhesive lapping and polishing discs. Told him all about this latest method of fine grinding, lapping and polishing metals. (he has an *enquiring* mind) . . .

When his Board heard how HYPREZ and ENGIS products not only did all this much better, but much more economically, too, Hargreaves was *made*.

All this was six weeks ago . . . hey, you'd better get hold of *your* copy now!

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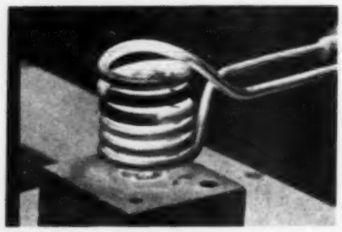

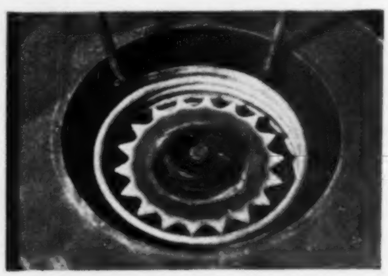

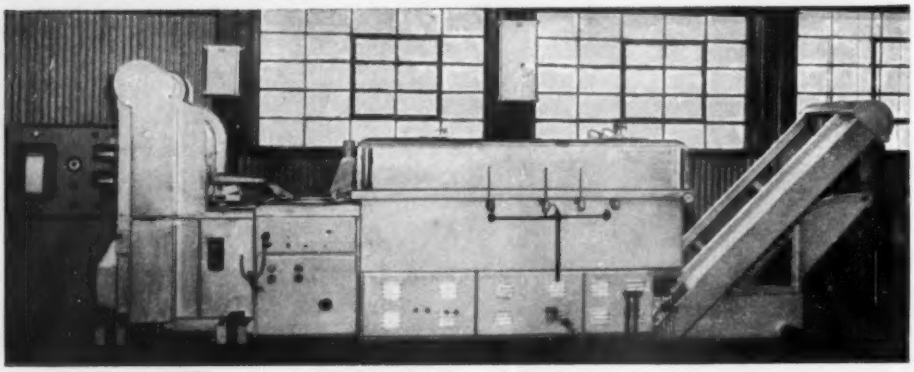

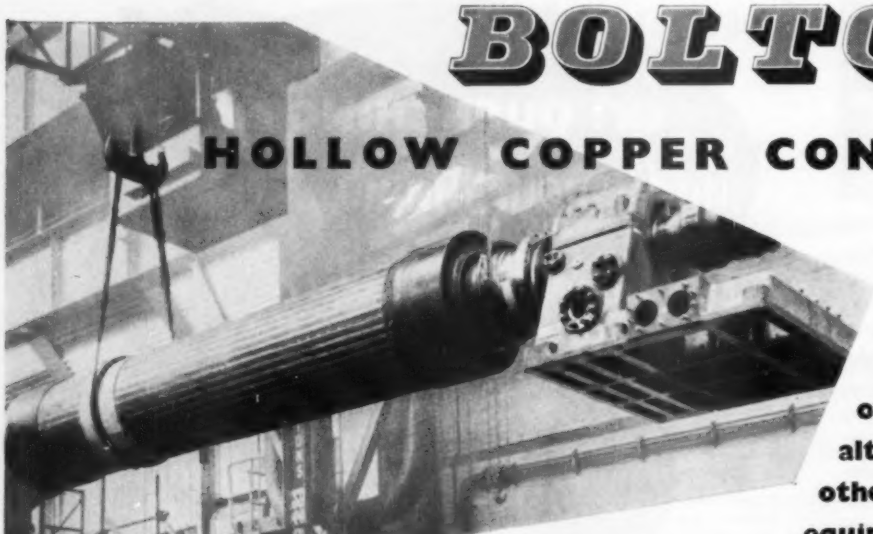

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Applications should be made to Personnel Officer, BICC Ltd., 38, Wood Lane, London, W.12.

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POST B in the TECHNICAL DEPARTMENT (METALLURGICAL SECTION), will involve technical control of fuel element manufacturing for which knowledge of modern vacuum melting and casting techniques, heat treatment and welding of the newer metals, would be an advantage. (Ref. SF.83/J.15).

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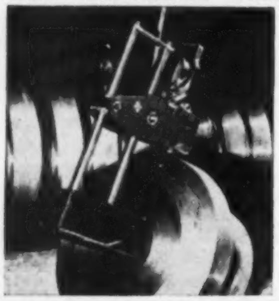

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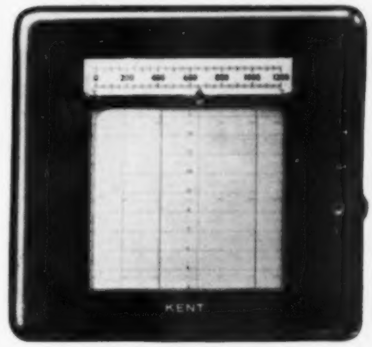
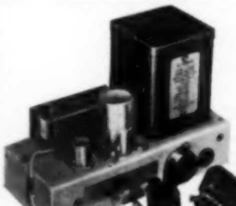


"Mark 3" indicator-recorder

"Commander KE" indicator-recorder

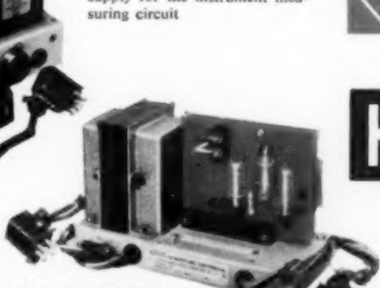
Both these modern high-speed indicator-recorders offer every user-advantage: plug-in modular construction, maximum accessibility, minimum maintenance etc. Both are available also as automatic controllers. Common electronic systems are employed, and the KENT series of amplifiers provides for a wide range of input conditions in temperature (thermocouple etc.), millivoltage, oxygen-percentage and electrolytic-conductivity measurement. The **Mark 3**—strip-chart recording—is available in up to 16-point form, depending on application. Both instrument types, in potentiometric version, incorporate the latest Zener-diode reference unit, which dispenses with standard cell etc.

Write or telephone (Luton 2440) for descriptive literature today.



"Type 3" Reference Unit

An extremely accurate constant-voltage source providing the necessary highly stable d.c. supply for the instrument measuring circuit



"Type 1" Quadrature Suppressor

Based on the KENT-patented thermistor potentiometer, this unit eliminates any quadrature component in the amplifier input (conductivity and electro-magnetic flow measurement)

KENT

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Cables and Telegrams: Kents Luton Telex

Registered Office 199-201 High Holborn, London, W.C.1

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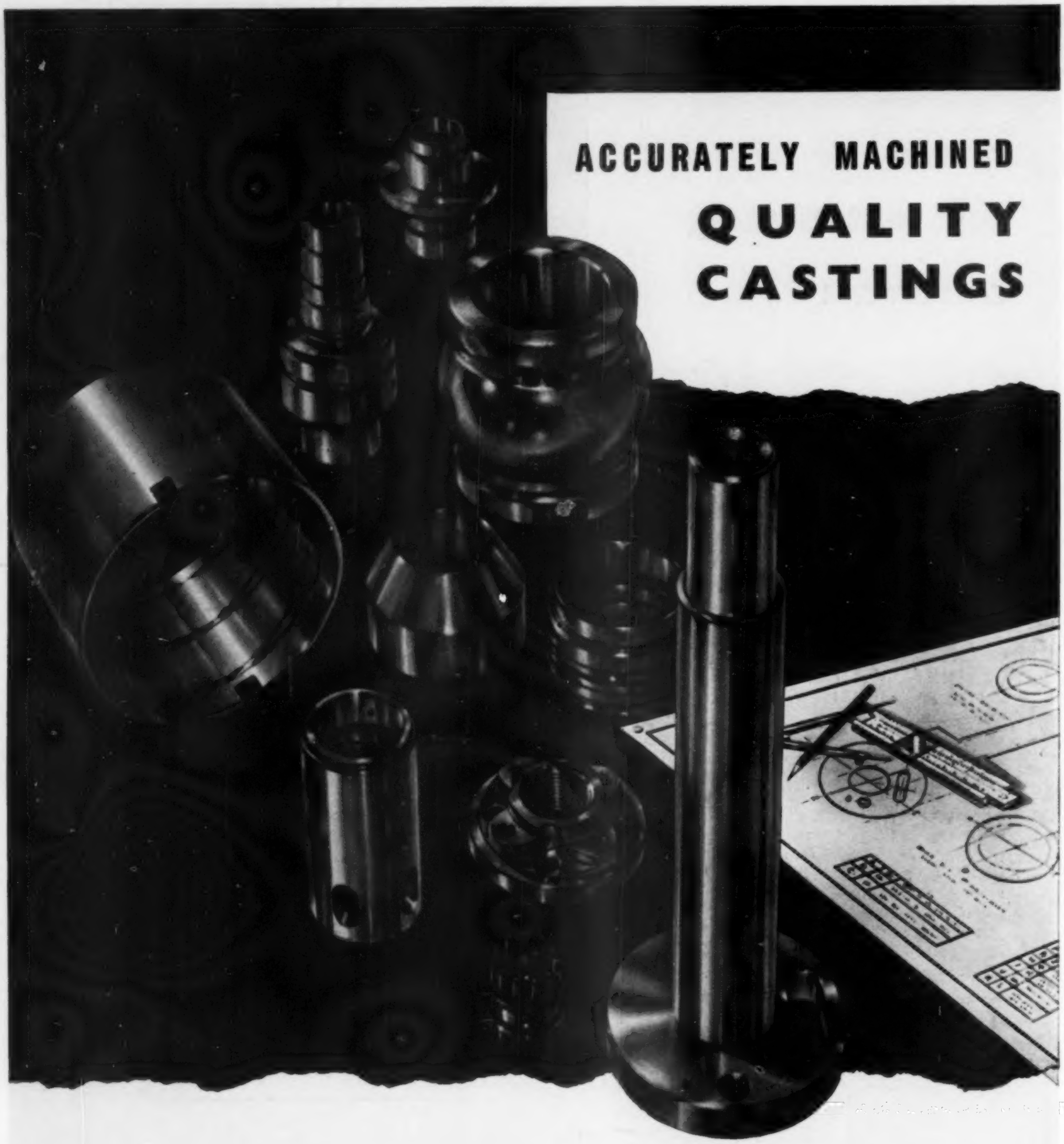
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